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Ore deposits and other classic localities in the Eastern Carpathians: From metamorphics to volcanics

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1. Geological introduction

1.1 General geological setting

by Ovidiu Gabriel Iancu & Marinel Kovacs

1.1.1 General structure and evolution of the Romanian Carpathians

The Carpathians are a segment of the Tethyan Chains; they join the Alps towards the West, and the Balkans and the Rhodope towards the South and the South-East. The Carpathian Foreland includes several platforms (such as the Scythian, Moesian ones) or cratons (such as the East European one) as well as the Cimmerian North Dobrogea Orogen.

The Carpathian Mountains are an almost semicircular mountain belt, 1500 km long and 50–150 km wide. The Carpathians are divided into the Eastern Carpathians, Southern Carpathians and Apuseni Mountains. Although the Carpathian orogenic belt appears to form a continuous easterly arc through Romania (Fig. 1), this belt formed through a series of events that began in Triassic time and continued to the present (Burchfiel *et al.*, 1974).

The Carpathian Folded Area is the result of several tectonogenetic events of different ages: Cretaceous (generating the Inner Zones named Dacides) and Miocene (the Outer Zones named Moldavides). Upper Cretaceous and/or Paleogene post-tectonogenetic covers develop above the Inner Zones. The Pannonian and the Transylvanian Neogene molassic depressions overlie important parts of the Inner Zones and a part of their post-tectonogenetic covers. A Neosarmatian-Eopleistocene molassic asymmetric foredeep develops in front of the Orogen, partly (inner limb) juxtaposed on its external zones (Săndulescu & Dimitrescu, 2004).

The general architecture of the Carpathian orogen includes the Median, Outer and Marginal Dacides (Săndulescu, 1984). In the Eastern and Southern Carpathians, the Median Dacides encompass vast areas of pre-Mesozoic metamorphic–magmatic basement complexes and Mesozoic sedimentary sequences. The Outer Dacides consist of a thrust sheet complex of

Cretaceous turbidites and ophiolites, while the Marginal Dacides are the most external units, present only in the Southern Carpathians and represented by the Mesozoic–Paleozoic cover sequences overlaying Precambrian basement. Alternative terms include the "Transilvanides" for the Vardar–Mureş oceanic domain, "Getides" for parts of the Median Dacides, "Severinides" for the Outer Dacides and "Euxinides" for the Danubian crust attached to the mobile margin of the Euxinic microplate (Balintoni, 1997b).

The Southern Carpathians

The Southern Carpathians consist of a Tertiary sedimentary cover, Mesozoic sedimentary deposits, volcano-sedimentary successions and related magmatic rocks, and a pre-Mesozoic basement.

The Mesozoic sedimentary deposits, the volcano-sedimentary formations and the related magmatic rocks compose the Cretaceous nappe piles, together with pre-Mesozoic terranes incorporated in basement units. The Cenozoic sediments seal the fold and thrust belt related structures, filling extensional sedimentary basins in internal areas and sealing also the intra-Sarmatian contact with the Moesian Platform. The main nappe complexes identified in the Cretaceous contraction stages include, from bottom to top, the Danubian, Severin and Getic-Supragetic nappes. Except for the Severin nappe complex, composed of Mesozoic ophiolites and sedimentary rocks, the other units consist of pre-Mesozoic metamorphic-magmatic basement and discontinuous Upper Carboniferous-Permian continental deposits discontinuously overlain by Mesozoic sedimentary successions.

The pre-Mesozoic basement of the Southern Carpathians includes the Palaeozoic and Neoproterozoic metamorphic terrenes, preserved in the Alpine Danubian and Getic-Supragetic Nappes. These nappes had been emplaced during two contraction stages related to convergence-collision events, in the Middle-Late Cretaceous time (Iancu *et al.*, 2005).

The Eastern Carpathians

Structurally, the Eastern Carpathians contain, from top to bottom, various nappes starting with the Transylvanian nappes and the Bucovinian nappes *s.l.* The latter are divided into the Bucovinian Nappe *s.s.*, the Sub-Bucovinian Nappe and the Infrabucovinian nappes. Towards the East, the Bucovinian nappes *s.l.* are thrusted over several flysch nappes (Black Flysch unit, Baraolt and Ceahlău nappes) (Săndulescu, 1984). The term "Transylvanian nappes" is a generic term for all the tectonic units emplaced on top of the Bucovinian Nappe *s.s.* Subordinate terms are Hăghimaş Nappe, Perşani Nappe and Olt Nappe (Hoeck *et al.*, 2009).

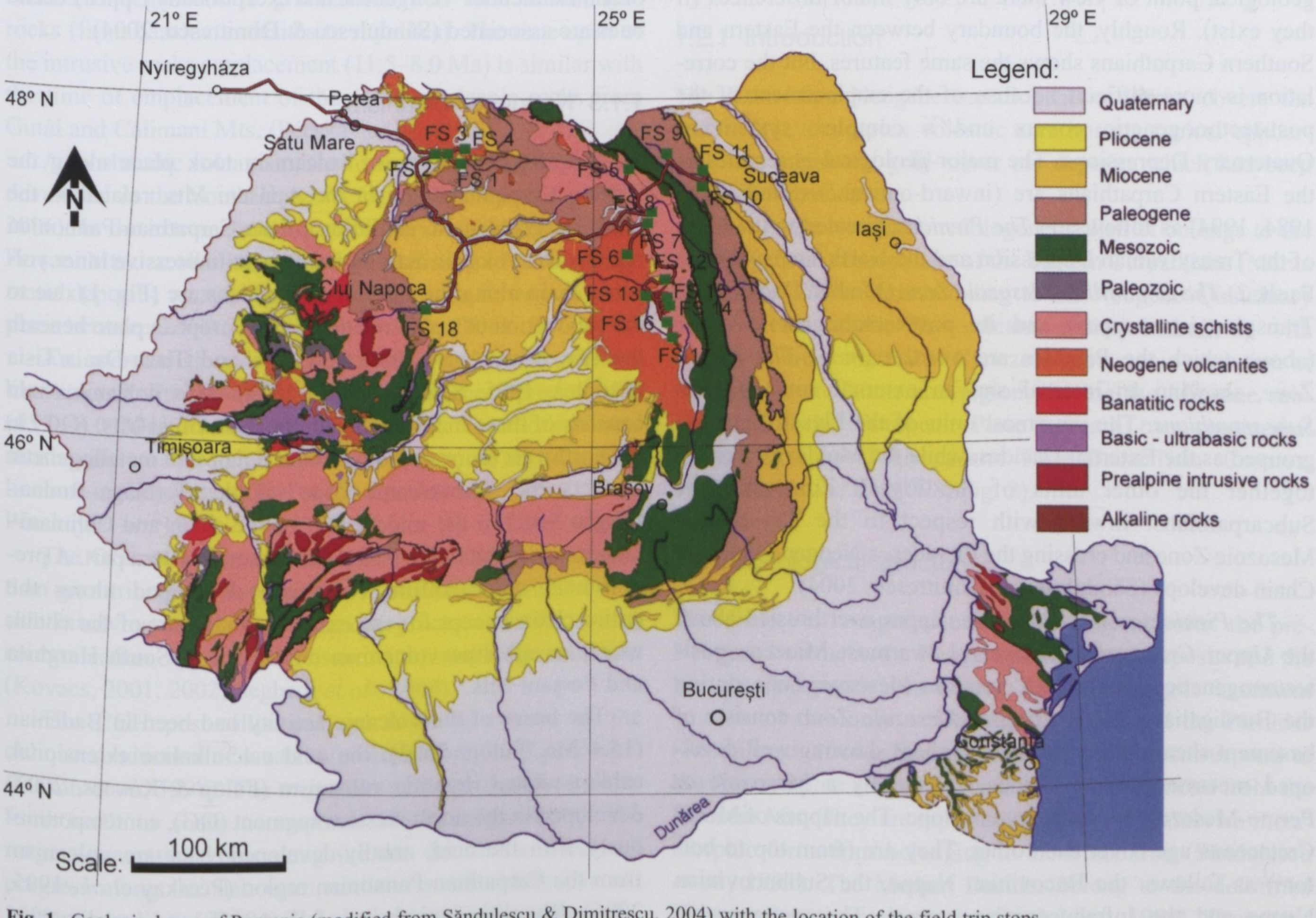

Fig. 1. Geological map of Romania (modified from Săndulescu & Dimitrescu, 2004) with the location of the field trip stops.

The Apuseni Mountains are situated in central Romania, north of the Southern Carpathians and west of the Transylvanian basin. They consist of two different structural elements, the Northern and Southern Apuseni Mts.. The tectonic units that build up the northern segment of the Apuseni Mts. are generically termed as the Apusenides. They are derived from the sheared margin of the Preapulian block at the western side of the Tethys Ocean (Săndulescu, 1984). According to their provenance and lithological content they were grouped in two nappe systems, thrust on top of the Bihor Autochthonous: the deeper Codru nappe system and the tectonically higher Biharia nappe system (Ionescu *et al.*, 2009). The Southern Apuseni tectonic units form a sequence of nappes called the Mureş Zone (Bleahu, 1976; Burchfiel, 1976) or the "Transylvanides" (Săndulescu, 1984). The Mureş Zone of Southern Apuseni Mts. consists of ophiolites, island arc volcanics and Wildflysch sediments, all of Jurassic and Cretaceous age, respectively (Hoeck *et al.*, 2009).

1.1.2 Geological structure of the Eastern Carpathians

The Romanian Eastern Carpathians are the natural southward prolongation of the Ukrainian East Carpathians. Conventionally the boundary between the Eastern and Northern Carpathians is situated along the Dniester, San and Uzh valleys, but from the geological point of view there are only minor differences (if they exist). Roughly, the boundary between the Eastern and Southern Carpathians shows the same features, but the correlation is more difficult because of the emplacement of the post-tectonogenetic covers and a complex system of Quaternary Depressions. The major geological ensembles of the Eastern Carpathians are (inward-outward) (Săndulescu, 1984, 1994) as follows: 1) *The Pienides*, situated to the north of the Transylvanian Depression and the North Transylvanian Fault; 2) *The Crystalline-Mesozoic Zone* (Median Dacides and Transylvanian nappes) and its post-tectonogenetic cover (above which the Pienides are overthrust); 3) *The Flysch Zone*, showing an internal and an external zone; 4) *The Subcarpathians*. The innermost units of the Flysch Zone are grouped as the External Dacides, while the Moldavides group together the other units of the Flysch Zone and the Subcarpathians. Inward with respect to the Crystalline-Mesozoic Zone and crossing the Pienides, a Neogene Volcanic Chain develops (Săndulescu & Dimitrescu, 2004).

The Pienides consist of cover nappes overthrusted above the Upper Cretaceous-Paleogene-Lowermost Miocene post-tectonogenetic cover of the Crystalline Mesozoic Zone, during the Burdigalian. *The Crystalline-Mesozoic Zone* consists of basement shearing nappes, each of them showing well developed metamorphic formations covered by a Mesozoic or Permo-Mesozoic sedimentary envelope. The nappes of Meso-Cretaceous age cover each other. They are (from top to bottom) as follows: the Bucovinian Nappe, the Subbucovinian Nappe and the Infrabucovinian nappes. The metamorphic rocks consist of several juxtaposed series (partially tectonically juxtaposed as a result of the Paleozoic tectonic events) (Kräutner, 1983, 1985; Balintoni, 1985, 1997a). The most important part of them is mesometamorphic and Precambrian as age. The youngest one (Tulgheş terrane) is Ordovician (Balintoni *et al.*, 2009). The Transylvanian nappes proceed from the Main Tethyan Suture Zone obducted during the Meso-Cretaceous tectogeneses. There are three main nappes (Perşani, Olt and Hăghimaş) with different lithostratigraphic successions and ages of the ophiolitic complexes from the basal part of the nappes (except for the Perşani nappe proceeding from the rifting zone, which preceded the opening of the Tethyan Ocean). Transitional successions between these three basic units may be also recorded. The Flysch Zone groups together cover nappes built up essentially of sedimentary formations detached from their primary basement and overthrusted eastward above the underthrust Foreland. The innermost nappes (Black Flysch, Ceahlău, Baraolt etc.) contain only Tithonian-Cretaceous formations, the Paleogene nappes building up their posttectonogenetic cover. The other units (the Moldavides) (Convolute Flysch, Macla, Audia, Tarcău, Marginal Folds) comprise Cretaceous, Paleogene and Miocene (Lower and Middle) sedimentary formations. The Subcarpathian Nappe is the outermost overthrust unit of the Eastern Carpathians. It consists mostly of Miocene formations to which – in the core of some anticlines – Oligocene and exceptionally Upper Eocene ones are associated (Săndulescu & Dimitrescu, 2004).

1.1.3 Neogene volcanism

A Neogene to Quaternary volcanism took place along the Eastern Carpathians and in the Apuseni Mts. related to the Neogene geotectonic evolution of the Carpathian-Pannonian region. The volcanic activity built up an impressive inner volcanic chain along the Eastern Carpathians arc (Fig. 1) due to the subduction of a slab related to the European plate beneath the two lithospheric blocks, Alcapa and Tisza-Dacia/Tisia (Csontos, 1995, Seghedi *et al.*, 1998). This volcanic chain consists of three main segments: the Oas–Gutâi Mts. (OG) in the northwest (corresponding to the Baia Mare metallogenetic district), the "Subvolcanic Zone" (Ţibleş–Toroiaga–Rodna–Bârgău Mts.) in the middle part of the chain and Călimani–Gurghiu–Harghita Mts. (CGH) in the southeastern part. A predominant calc-alkaline volcanism developed along the entire chain except for the extreme south part of the chain, where an alkaline volcanism developed in South Harghita and Perşani Mts.

The onset of the volcanic activity had been in Badenian (15.4 Ma, Fülöp, 2003): the acid calc-alkaline extensional, caldera-related rhyolitic volcanism (Fülöp & Kovacs, 2003) developed in the north-western segment (OG), contemporaneously with the acid, areally-developed, back-arc volcanism from the Carpathian-Pannonian region (Pécskay *et al.*, 1995, 2006). Rhyolitic ignimbrites, fallout tuffs and resedimented volcaniclastics crop out in the southwestern part of the Gutâi Mts. (Fülöp, 2003) and in the Transylvanian Basin where they form the so called "Dej Tuff Complex" (Szakács , 2000).

An intermediate calc-alkaline, arc-type volcanism built up the main volcanic structures of the Eastern Carpathians volcanic chain. It started in Gutâi Mts in Sarmatian (13.4 Ma, Edelstein *et al.*, 1992a) and developed continuously along the whole chain until Quaternary (<1.0 Ma, Pécskay *et al.*, 2006). In OG, the volcanism had taken place between 13.4–7.0 Ma with a paroxystic phase in the 11.0–9.0 time interval (Kovacs & Fülöp, 2003, Pécskay *et al.*, 2006). The volcanic structures from the OG are mostly eroded but they are quite well preserved in the CGH. Volcano-tectonic depression fillings, extrusive domes as well as lava plateau are the predominant volcanic forms in OG (Kovacs *et al.*, 2006). The stratovolcanoes (with or without caldera), the effusive cones and domes are predominant in CGH (Szakács & Seghedi, 1995). Andesites and basaltic andesites are the prevalant volcanic rocks in the both two segments.

The "Subvolcanic Zone" of the Eastern Carpathians volcanic chain is located between the OG (NW) and CGH (SE) segments. It consists exclusively of intrusive rocks from the Ţibleş, Toroiaga, Rodna and Bârgău mountains. The intrusive bodies form stocks, laccoliths, dykes and sills with different sizes and shapes consisting of a series of typical intrusive rocks (from gabbros to granodiorites) as well as volcanic rocks (from basaltic andesites to rhyolites). The time-span of the intrusive rocks emplacement (11.5–8.0 Ma) is similar with the time of emplacement of the nearest volcanic rocks from Gutâi and Călimani Mts. (Pécskay *et al.*, 2009).

A shoshonitic volcanism, shallow intrusions of 2.2–1.2 Ma developed in the South Harghita Mts. (Pécskay *et al.*, 1995, 2006). In the extreme south part of the volcanic chain, in the Perşani Mts., an alkaline volcanism consisting of phreatomagmatic deposits, maars, scoria cones and lava flows had taken place between 1.5–0.5 Ma (Pécskay *et al.*, 2006).

An intermediate calc-alkaline with transition to adakite-like calc-alkaline volcanism occurred in the Apuseni Mts. (15.0–8.0 Ma, Pécskay *et al.*, 2006); an alkaline and shoshonitic small volume volcanism post-dated the calc-alkaline one in the southern part of the Apuseni Mts. (2.5–1.5 Ma, Pécskay *et al.*, 1995, 2006).

The OG volcanism and the "Subvolcanic Zone" magmatism are attributed to a subduction-related rollback of a normal slab involving complex petrogenetic processes as the source contamination, upper crustal assimilation and magma mixing (Kovacs, 2001, 2002; Seghedi *et al.*, 2004).

The CGH post-collisional volcanism is related to the oblique subduction of a narrow slab and break-off processes (Mason *et al.*, 1998). The migration of the magmatic activity from north to south corresponds to the migration of the magma-generating zone along the arc due to the break-off progress along the slab from north to south (Mason *et al.*, 1998; Seghedi *et al.*, 2004).The almost contemporaneous calc-alkaline and adakite-like calc-alkaline, shoshonitic and alkaline basaltic volcanism from the extreme south part of the segment (South Harghita and Perşani Mts.) is related to some unusual magma-generating conditions (break-off and tearing of the slab at shallow levels, strike-slip tectonics and extensional stress regime according to Seghedi *et al.*, 2004).

Apuseni Mts. volcanism, with transition from typical calc-alkaline to adakite-like calc-alkaline is related to decompressional melting of the lower crust and /or of the enriched lithospheric mantle in an extensional regime (during translation and rotation of the Tisia block, according to Seghedi *et al.*, 2004). Important hydrothermal gold-silver and base metal ore deposits occur in the north-western segment (OG/Baia Mare district) as well as in the Apuseni Mts. (porphyry type developed here besides the epithermal type). Hydrothermal polymetallic ore deposits of less economic importance are known also in the "Subvolcanic Zone". Different non-economic mineralisations of hydrothermal (base metal, gold-silver and cinnabar), porphyry copper and solfataric-hydrometasomatic (native sulphur) types developed in CGH related to the complex volcanic structures (Seghedi *et al.*, 1994).

1.2. Baia Mare Neogene metallogenetic district

by Marinel Kovacs & Alexandrina Fülöp

1.2.1 Introduction

The Baia Mare Neogene metallogenetic district covers the Gutâi Mts., a complex volcanic area hosting typical epithermal base metal and gold–silver ore deposits which had been mined for centuries.

Baia Mare Neogene metallogenetic district belongs to the metallogenetic subprovince of the Eastern Carpathians (Mârza & Kovacs, 2004) corresponding to the Neogene–Quaternary inner volcanic chain. This volcanic chain was built up with respect to the complicated Cenozoic geotectonic evolution of the Carpathian–Pannonian region, driving the Miocene subduction of the European Plate beneath two continental blocks/microplates, Alcapa and Tisza–Dacia/Tisia (Csontos, 1995; Seghedi *et al.*, 1998, Fig. 2).

1.2.2 Geological structure

The district is composed of three geological units: the pre-Neogene basement, the Neogene sedimentary deposits and the Neogene magmatic succession. The pre-Neogene basement consists of the Inner and Median Dacides and the Pienides (Săndulescu, 1984). The Inner Dacides, which correspond to the Austroalpine nappes of the Eastern Alps, extend from the Apuseni Mts. They are represented by the Precambrian metamorphic formations belonging to the Bihor Unit (Săndulescu *et al.*, 1993). The Median Dacides belong to the deformed European continental margin (Săndulescu, 1984). They con-

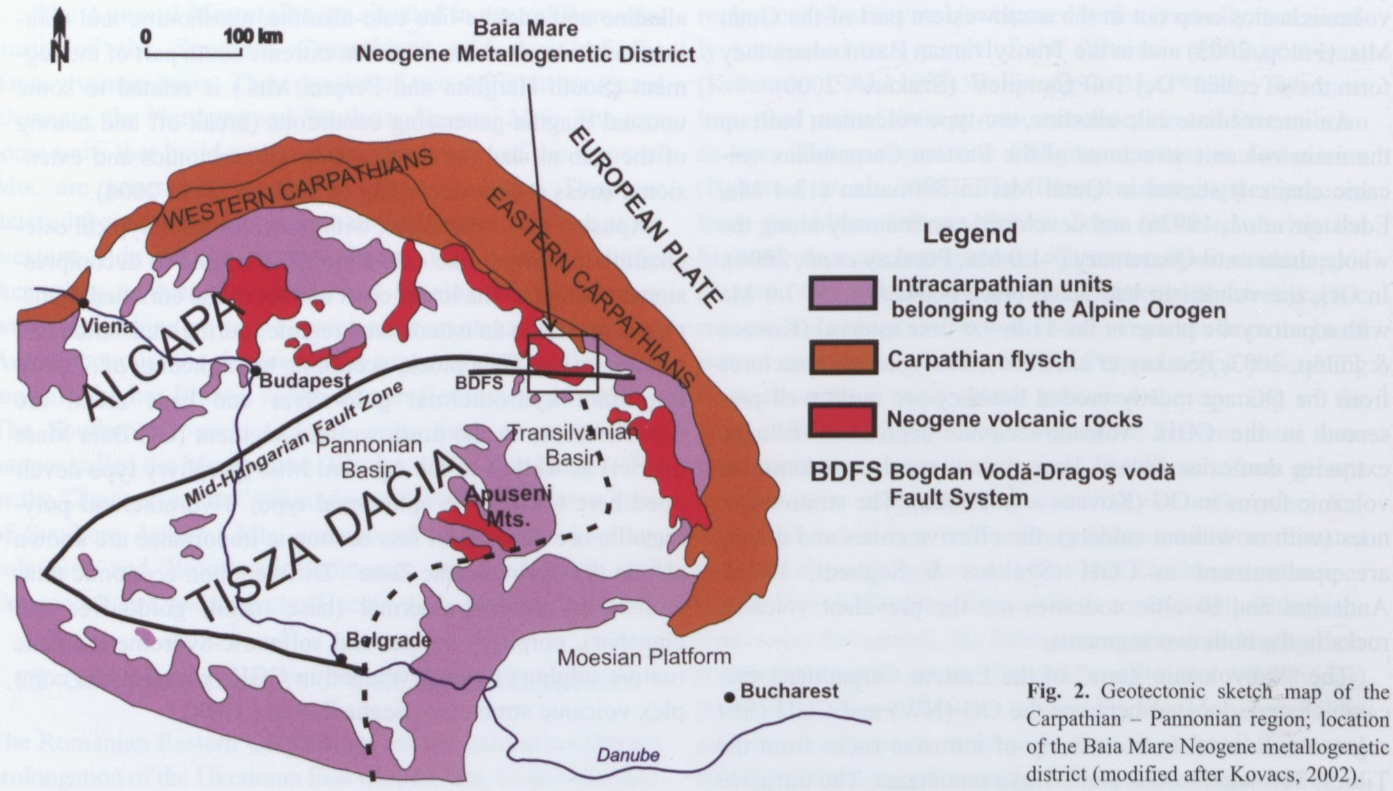

Fig. 2. Geotectonic sketch map of the Carpathian – Pannonian region; location of the Baia Mare Neogene metallogenetic district (modified after Kovacs, 2002).

sist of the Precambrian–Paleozoic metamorphic formations which are outcropping towards the south-eastern part of the Baia Mare district and are intersected by boreholes underneath the Neogene volcanics. The Pienides consist of several overthrusted units composed of the Paleogene flysch formations which are outcropping extensively in the eastern part of the Baia Mare district (Fig. 3) and lie beneath the whole district, as intercepted by the underground exploration works. Small outcrops occur towards the west, suggesting the elevation of the basement. The Pienniny Klippen Zone (Jurassic–Upper Cretaceous), occur in front of the Botiza Nappe, south-east of the volcanics zone (Fig. 3).

The Neogene sedimentary deposits are composed of Badenian, Sarmatian and Pannonian rocks and in general are covered by the Neogene volcanics. The sediments crop out only on small areas in the Gutâi Mts. They are interbedded with volcaniclastic products building up thick volcano-sedimentary sequences accounting for the coeval evolution of the sedimentary and volcanic processes. The Late Badenian (Kossovian) deposits are mudstones interbedded with coarse rhyolitic volcaniclastic deposits. The Sarmatian deposits (Volhynian and Bessarabian) consist of mudstones and siltstones interbedded with sandstones and volcaniclastics of both explosive and non-explosive origin. The Badenian rhyolitic pyroclastic deposits can be identified as reworked volcaniclastics interbedded by the Early Sarmatian sediments. The Sarmatian andesitic volcaniclastics, both pyroclastics and hyaloclastic are interbedded with the Upper Sarmatian sediments proving for the onset of the intermediate volcanism during the Sarmatian. The lithology of the Pannonian sedimentary deposits resembles partially with the lithology of the Sarmatian sedimentary deposits, with abundant mudstones and siltstones often interbedded with various intermediate volcaniclastics. Instead, on top of the Pannonian succession, the lithology changes to coarser terms consisting of sandstones and microconglomerates interbedded with rare coal layers.

The most important tectonic feature of the area is the W–E trending Bogdan Vodă–Dragoş Vodă fault system (BDFS, Fig. 1) located in the southern part of the Gutâi Mts. (Săndulescu, 1984; Borcoş, 1994; Tischler *et al.*, 2006). It is regarded as a prolongation of the Mid-Hungarian line (Csontos & Nagymarosy, 1998, Tischler *et al.*, 2006). Győrfi *et al.* (1999) documented that along the "Dragoş Vodă fault", important extensional movements took place. NE–SW and NW–SE oriented fractures related to this tectonic structure separated a series of horsts and grabens in the basement of the volcanic area (Borcoş *et al.*, 1979; Borcoş, 1994).

1.2.3 Volcanology and petrology

The Neogene magmatic succession is attributed to two distinct types of volcanism: a) the acid, extensional/"back–arc"volcanism and b) the intermediate, arc–type volcanism (Kovacs & Fülöp, 2003) corresponding to the complex subduction processes and the hinterland reply, respectively.

Overall, there is a time–space migration of the volcanism, parallel to the volcanic front of the subduction zone (Kovacs *et al.*, 2006).

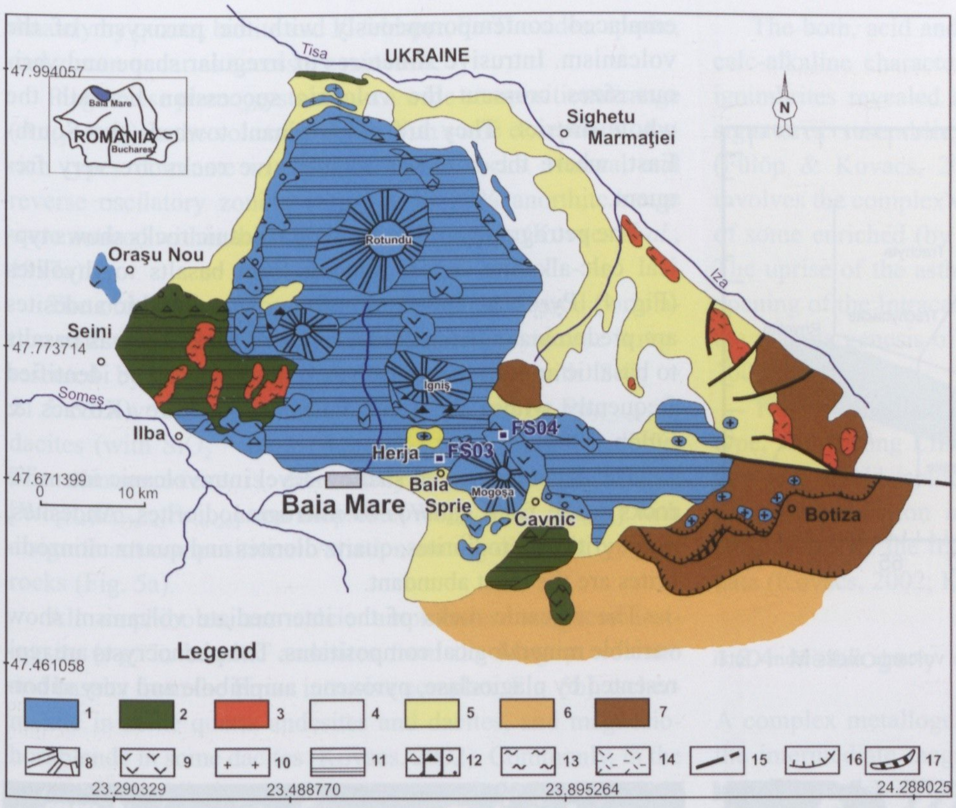

Fig. 3. Simplified volcanological map of the Gutâi Mts. (modified after Kovacs *et al.*, 2006).
1 – Pannonian volcanics; 2 – Sarmatian volcanics; 3 – Badenian volcanics; 4 – Quaternary; 5 – Neogene sedimentary deposits; 6 – Oligocene-Miocene sedimentary deposits; 7 – Paleogene sedimentary deposits; 8 – Effusive cones; 9 – Extrusive domes; 10 – Intrusions; 11 – Volcano-tectonic depression filling; 12 – Pyroclastic and epiclastic deposits; 13 – Ignimbrites and associated volcaniclastics; 14 – Primary and reworked tuffs; 15 – Faults; 16 – Overthrusts; 17 – Pieniny Klippen Zone.

The acid, rhyolitic volcanism started 15.4 Ma ago. The explosive, caldera–type of volcanism (Fülöp, 2003) is correlated partially with the widespread rhyolitic volcanism of the Pannonian Basin. The suite of volcaniclastic deposits of pyroclastic origin are typically divided into two distinct sequences: the basal ignimbrite sheet, locally mantled by co-ignimbrite fallout tuffs and the upper, complex succession composed of reworked volcaniclastics of pyroclastic origin interbedded with mudstone. The thick and narrow welded ignimbrite sheet is thinning from the West to the East settling over the Paleogene basement along the southern part of the Gutâi Mts. (Fig. 3) On top of it, patchily distributed sequences consisting of volcaniclastics of mass flow origin interbedded with mudstone were built up by synergistically syn- and post-eruptive erosion and reworking, volcanic subsidencing and sedimentation, active for around 2 Ma. The whole felsic succession, reaching 700 m in places, can be identified and studied exclusively in drill cores.

The acid volcanics, whether primary or reworked, are typically rhyolite pyroclastics (Fülöp & Kovacs, 2003). The components show insignificant variations in grain size and abundance. The juvenile components, pumice, glass shards and crystals of plagioclase ($An_{28–47}$), quartz and biotite (intermediate terms of phlogopite–annite series with high Fe/Mg ratio) are predominant. Cognate non-vesicular glassy clasts are rare, unlike accidental clasts of sedimentary and metamorphic rocks which are abundant. Pyroxene andesite accidental lithic clasts and pyroxene crystal clasts are rare (Fülöp & Kovacs, 2003).

The intermediate volcanics followed the acid pyroclastics in the complex succession of rocks building up Gutâi Mts. The emplacement of the intermediate, volcanic suite lasted much longer than the built up of the felsic succession (13.4–7.0 Ma, according to Pécskay *et al.*, 1995). It was contemporaneous with the volcanism developed in Tokaj Mts., Vihorlat Mts. and Transcarpathia. Mostly extrusive, the intermediate volcanism started in the south-eastern and south–western part of the mountains during the Sarmatian (13.4–12.1 Ma, according to Edelstein *et al.*, 1992a and Pécskay *et al.*, 1994), spreading towards N, NW and NE during the Pannonian (12.0–9.0 Ma, Pécskay *et al.*, 2006). A mafic intrusive phase consisting of pyroxene basalts, dated between 8.1–7.0 Ma (Edelstein *et al.*, 1993), ceased the volcanic activity in the area.

Distinct effusive cones, lava plateaus and domes can be recognized but most of the volcanic structures overlap and hide the older morphologies (Fig. 3). Fragmental, explosive and non-explosive processes developed contemporaneously with the emplacement of the coherent volcanics building up thick piles of lavas interbedded with pyroclastic and hyaloclastic deposits. The rootless explosions are very common, as well as quench fragmentation and the subsequent episodes of resedimentation developed as consequences of the submarine emplacement of most of the lavas. The quiet periods of volcanic calm are responsible for the active sedimentation, which filled up the local depressions with thick volcaniclastic and epiclastic sediments.

An intrusive activity developed along with the intermediate, extrusive volcanism. Most of the intrusions were

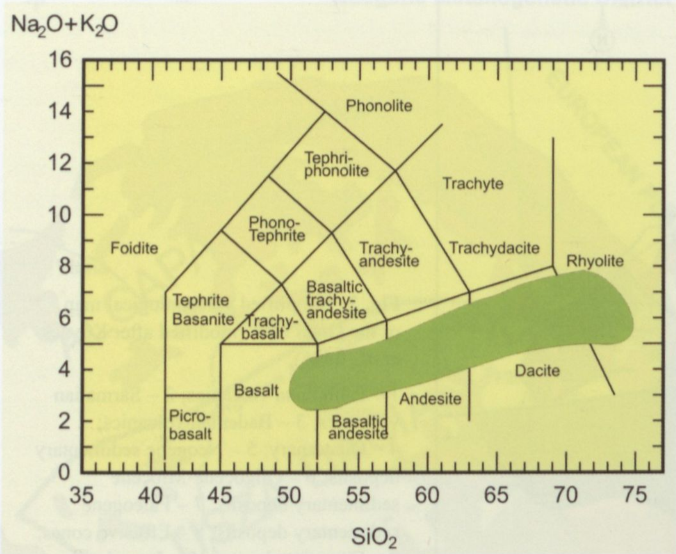

Fig. 4. Distribution of the acid and intermediate volcanic rocks from Gutâi Mts. in TAS diagram (Kovacs & Fülöp, 2003).

emplaced contemporaneously with the paroxysm of the volcanism. Intrusive structures of irregular shape and various sizes crosscut the volcanic succession beneath the whole district. They are predominant towards the South-East, where the outcrops of intrusive rocks are very frequent.

The petrography of the arc-type volcanic rocks shows typical calc-alkaline series, ranging from basalts to rhyolites (Fig. 4). Pyroxene andesites and pyroxene basaltic andesites are predominant. Transitional series of rocks such as basalts to basaltic andesites and dacites to rhyolites can be identified frequently within the same volcanic structure (Kovacs & Fülöp, 2003).

The subvolcanic and shallow-level intravolcanic intrusive rocks range from gabbros to microgranodiorites. Andesites, porphyritic microdiorites, quartz diorites and quartz monzodiorites are the most abundant.

The volcanic rocks of the intermediate volcanism show variable mineralogical compositions. The phenocrysts are represented by plagioclase, pyroxene, amphibole and very subor-

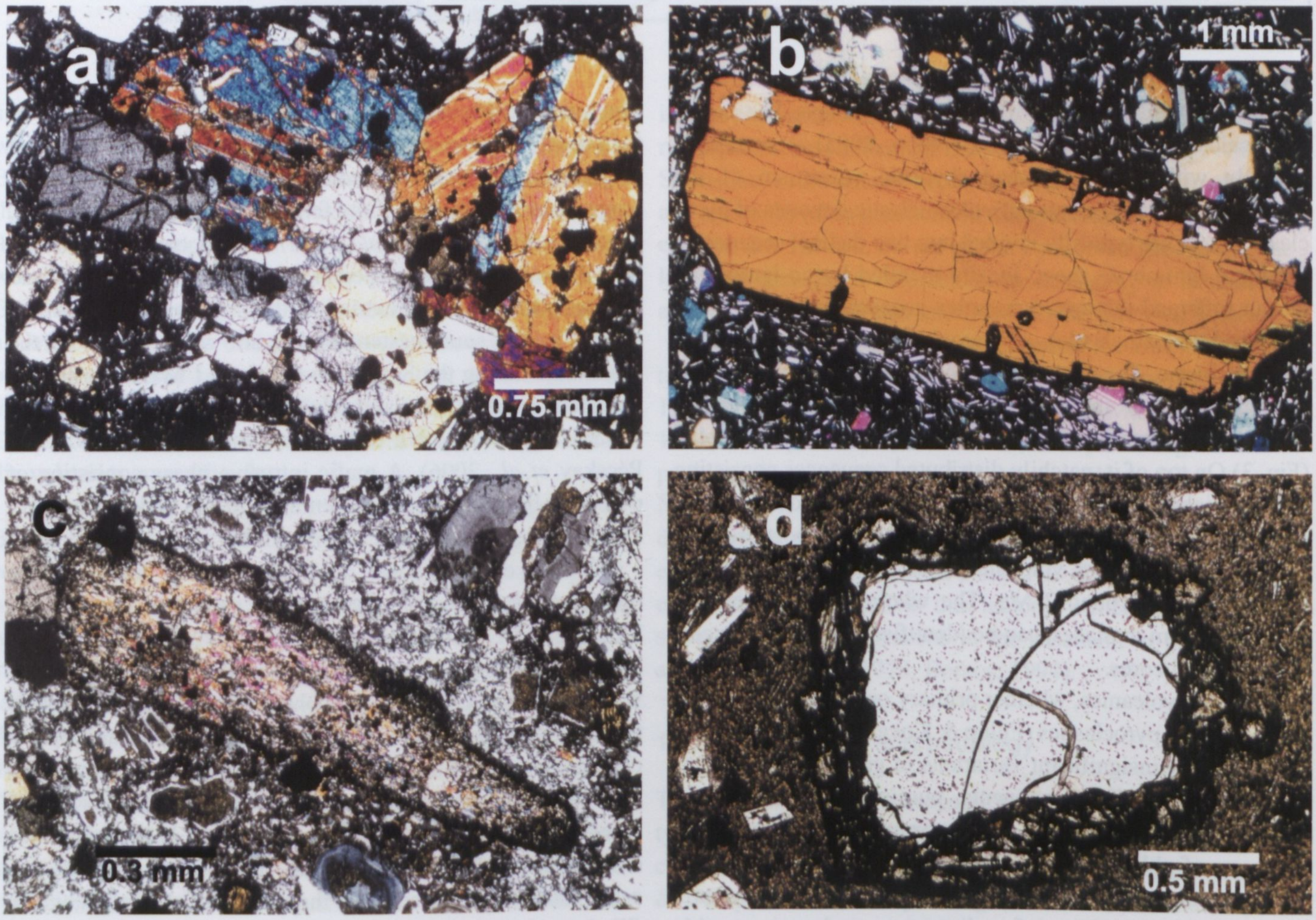

Fig. 5. Photomicrographs illustrating typical aspects of the minerals from different volcanic rock types in Baia Mare district (Kovacs, 2002). a) Twinned Al-Ti augite phenocrysts in basaltic andesites from Mogoşa volcano. b) Uncommon large phenocryst of amphibol (Ti-Mg hastingsite) from Firiza basalts. c) Amphibol phenocryst replaced by a mixture of clinopyroxen + plagioclase + Fe-Ti oxides in Şuior quartz andesites. d) Quartz phenocryst with pyroxene corona in andesites from Gutâi extrusive dome.

dinately by quartz, biotite and K-feldspar. Fe-Ti oxides, apatite, and zircon occur as accessory minerals.

Plagioclase phenocrysts shows a wide compositional range (An_{32}–An_{92}) in the volcanic rocks. With some exceptions, An-rich types dominate in the more basic rocks. Normal and reverse oscilatory zoning across a 30–35% anorthite range were noticed within the individual phenocrysts (Kovacs *et al.*, 1997a).

The orthopyroxene composition presents a good correlation with the volcanic rock type: *e.g.* the orthopyroxene is represented by $En_{71.4-61.7}$ in basaltic andesites (with SiO_2 = 51.5–55.5 wt%) from the Mogoşa volcano and by $En_{59.3-51.6}$ in dacites (with SiO_2 = 62.2–64.5 wt%) from the Breze dome. The clinopyroxene is dominantly represented by augite [$Wo_{27-45}En_{38-43}Fs_{16-20}$] and diopside [$Wo_{44-48}En_{40-46}Fs_{6-13}$] with a significant compositional variation among different types of rocks (Fig. 5a).

All amphiboles are calcic amphiboles: magnesiohastingsite (*e.g.* in basaltic andesites from the Mogoşa volcano and basalts from the Firiza intrusive complex, Fig. 5b), tschermakite in some quartz andesites and dacites, and magnesiohornblende in some dacites (Kovacs, 2002). Commonly, in the pyroxene-amphibole andesites, quartz andesites and dacites, the amphibole phenocrysts are replaced by a mixture of plagioclase, pyroxene and Fe-Ti oxides; Fig. 5c).

The presence of the plagioclase and quartz xenocrysts in various rock types, as well as the quartz phenocrysts with pyroxene coronas (Fig. 5d) and pyroxene clusters in some acidic rocks, indicates mixing and mingling processes which took place during the petrogenesis of the intermediate magmatic rocks (Kovacs, 2002).

The both, acid and intermediate types of volcanism show calc-alkaline character (Fig. 6a). The geochemical study of ignimbrites revealed a rhyolitic character with geochemical signatures resembling other subduction-related volcanics (Fülöp & Kovacs, 2003). The petrogenesis of ignimbrites involves the complex evolution in the crustal magma chamber of some enriched (by subduction components) mantle melts. The uprise of the asthenospheric mantle during the back–arc opening of the Intracarpathian region has been responsible for the magma genesis of this acid volcanism (Fülöp & Kovacs, 2003).

The intermediate volcanism is of subduction-related/arc-type, with strong LILE and LREE enrichment, HFSE depletion and Sr-Nd isotopes negative correlation (Fig. 6b). The crustal assimilation involving AFC processes was strongly constrained by the trace elements geochemistry and isotopic data (Kovacs, 2002; Kovacs & Fülöp, 2003).

1.2.4 Metallogeny

A complex metallogenetic activity had been associated with the intermediate magmatism in the Baia Mare district. The metallogenetic activity was responsible for the deposition of the epithermal mineralisations along the southern part of the Gutâi Mts. The mineralisations are of typical low-sulphidation type and consist of mainly polymetallic and gold-rich veins, and less breccia pipes/dykes and stockworks, respectively. The metallogenetic activity in the Baia Mare district was controlled by both tectonics and magmatism. The most important tectonic control was played by the major W–E trending transcrustal Bogdan Vodă–Dragoş Vodă fault

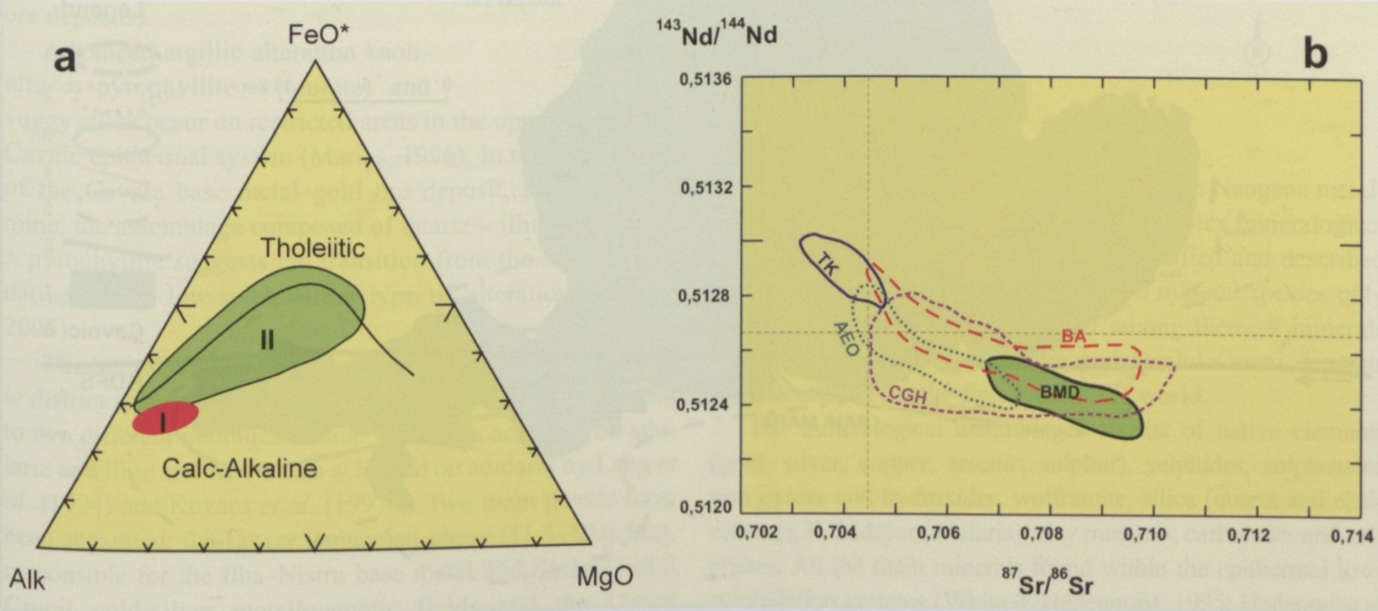

Fig. 6. a) Distribution of the acid (I) and the intermediate (II) volcanics from Gutâi Mts. in AFM diagram; b) Sr and Nd isotopic composition of the intermediate volcanic rocks from Baia Mare district (BMD) comparative with other subduction-related volcanic arcs: TK – Tonga–Kermadec arc; BA – Banda arc; AEO – Aeolian arc; CGH – Călimani–Gurghiu–Harghita (Eastern Carpathians) arc-type volcanics (according to Kovacs, 2002).

(Săndulescu *et al.*, 1993), or the Bogdan–Dragoş Vodă fault system (Tischler *et al.*, 2006), respectively, located in the southern part of the Gutâi Mts. (Fig. 7). The main epithermal ore deposits are disposed either along this transcrustal fault system or in some, NE–SW or NW–SE oriented, satellite tectonic structures (tensional fractures, predominantly). The magmatic control is connected with the pluton outlined by the geophysical data beneath the southern part of the district (Borcoş, 1994; Crahmaliuc *et al.*, 1995; Fig. 7). Most of the epithermal mineralisations from the Baia Mare district are genetically related to the intrusions developed in the ore deposits, thus being classified as "intrusion-related" epithermal systems.

More than 20 ore deposits developed in three main metallogenetic fields (Fig. 7). The Ilba–Nistru field is composed of base metal ore deposits, connected with the Sarmatian magmatism spread in the south-western part of the Gutâi Mts. The Săsar–Dealul Crucii field consists of a typical gold epithermal system located in the southern–central part of the mountains (northern from the city of Baia Mare). The Herja–Băiuț field, with base metal–gold ore composition, includes some of the most important deposits from the district, the Baia Sprie and Cavnic. The mineralisations belonging to the last two metallogenetic fields are connected with the Pannonian magmatism.

The mineralisations are hosted by various structures, exclusively magmatic (volcanic and/or intrusive rocks) or more complex (tectonomagmatic with sedimentary deposits). The Baia Sprie ore deposit is located within a thick sequence composed of andesite lavas and volcaniclastics. They fill a volcanotectonic depression/graben connected with the Bogdan–Dragoş Vodă fault system. The Cavnic ore deposit is hosted by volcanic, intrusive and sedimentary rocks. The gold-rich veins from the Săsar-Sofia ore deposit are exclusively developed in a ~1000 m thick volcanic sequence (Fig. 8) and the Herja base metal mineralisations are hosted by intrusions in an uplifted Paleogene basement zone (according to Iştvan *et al.*, 1986, Fig. 8).

The lengths of the veins reach from hundreds of meters to 5 km (*e.g.* the Principal Vein belonging to Baia Sprie ore deposit). The thickness of the veins ranges between 0.3 m to 10 m and the whole height of the mineralised level is between 300 and 1000 m. The vertical, well-displayed zonality, with Au-Ag on top, Pb-Zn in the middle part and Cu at the bottom is typical for some of the ore deposits of the Baia Mare district (*e.g.* Baia Sprie ore deposit).

A wide variety of textures were identified in the epithermal ore deposits from the Baia Mare district. Cavity-filling veins with sharp boundaries, typical for the low-sulphidation systems (White & Hedenquist, 1995) are the prevalent features. Different magmatic, phreatomagmatic and hydrothermal breccias developed in most of the ore deposits, *e.g.* breccia pipes in Cavnic, Şuior, Baia Sprie, Săsar, and breccia dykes in Cavnic and Baia Sprie ore deposits (Milési *et al.*, 1994; Genna *et al.*, 1994; Mariaş, 1996, 2005). Stockworks (*e.g.* Borzaş gold mineralisation in the Săsar ore deposit) and disseminated textures occur only within the gold-rich upper part of some ore deposits (*e.g.* Ilba, Nistru, Băița and Baia Sprie–Dealul Minei open pit). Banded and drusy textures are common in most of the veins.

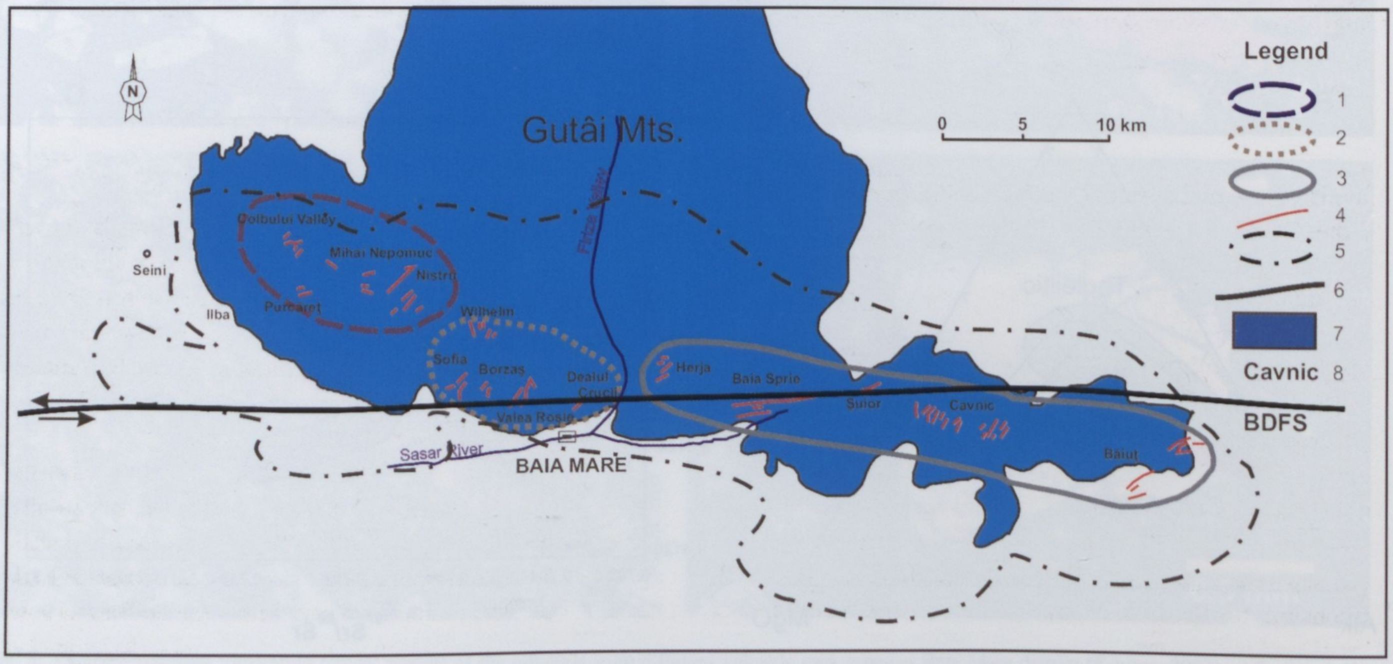

Fig. 7. Sketch map of the Baia Mare metallogenetic district with the main ore deposits. 1 – Ilba–Nistru base metal metallogenetic field; 2 – Săsar–Dealul Crucii gold-silver metallogenetic field; 3 – Herja–Băiuț base metal + gold metallogenetic field; 4 – Veins; 5 – Boundary of the underlying pluton; 6 – Bogdan–Dragoş Vodă fault system; 7 – Volcanic area of the Gutâi Mts; 8 – Ore deposit.

Collomorph and quartz–chalcedony finely banded textures developed in the Au-Ag mineralisation and in the upper part of the polymetallic mineralisation.

The hydrothermal alterations are predominantly of adularia-sericite type, in particular developed in the Ilba–Nistru and Săsar–Dealul Crucii metallogenetic fields. The mineralogy of the hydrothermal alteration zones is similar with the neutral pH alteration style of the low-sulphidation epithermal systems (Heald *et al.*, 1987; Reyes, 1990) with adularia, quartz, illite and smectite as dominant minerals and chlorite, calcite and kaolinite as subordinate minerals. The adularia is the most significant hydrothermal mineral of the area, usually occuring as a vug-filling phase within the veins (Fig. 9) or in their close vicinity.

The common alteration zoning showing silicic, adularia, phyllic (illite-smectite) and propylitic alterations was recorded outward from the veins, as for the great bulk of the epithermal ore deposits. Sometimes, the alteration zones are overprinted both laterally and in depth (Stanciu, 1973; 1984). High sulphidation alterations are locally developed in the eastern part of Gutâi Mts. (Cavnic–Jereapăn–Băiuț ore deposits).

Advanced argillic alteration kaolinite ± pyrophyllite ± alunite) and vuggy silica occur on restricted areas in the upper part of the Cavnic epithermal system (Mariaș, 1996). In the central part of the Cavnic base metal–gold ore deposit, in the Bolduț mine, the assemblage composed of quartz – illite – kaolinite ± pyrophyllite suggests the transition from the high-sulphidation to the low-sulphidation type of alteration (Mariaș, 2005).

The hydrothermal activity in the Baia Mare metallogenetic district spanned the Pannonian, *i.e.* 11.5–7.9 Ma, according to two different radiometric data: K-Ar data achieved on adularia and illite and Ar-Ar data achieved on adularia by Lang *et al.* (1994) and Kovacs *et al.* (1997b). Two main phases have been separated: the Lower Pannonian phase (11.5–10.0 Ma), responsible for the Ilba–Nistru base metal and Săsar–Dealul Crucii gold-silver metallogenetic fields and the Upper Pannonian phase (9.4–7.9 Ma), with the Herja–Băiuț base metal–gold metallogenetic field mineralisations (Kovacs *et al.*, 1997b).

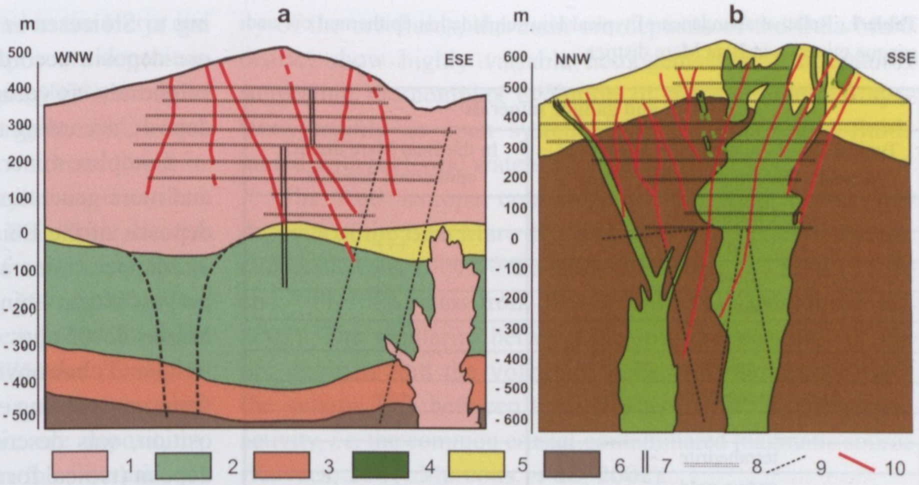

Fig. 8. Geological cross-sections through a) Săsar-Sofia and b) Herja mineralized structures (simplified after Iștvan *et al.*, 1986, 1994). 1 – Pannonian quartz andesites (lavas, volcaniclastics and intrusions); 2 – Sarmatian andesitic volcanics; 3 – Badenian rhyolitic volcaniclastics; 4 – Pannonian intrusions; 5 – Pannonian sedimentary deposits; 6 – Paleogene flysch; 7 – Shaft; 8 – Gallery; 9 – Borehole; 10 – Vein.

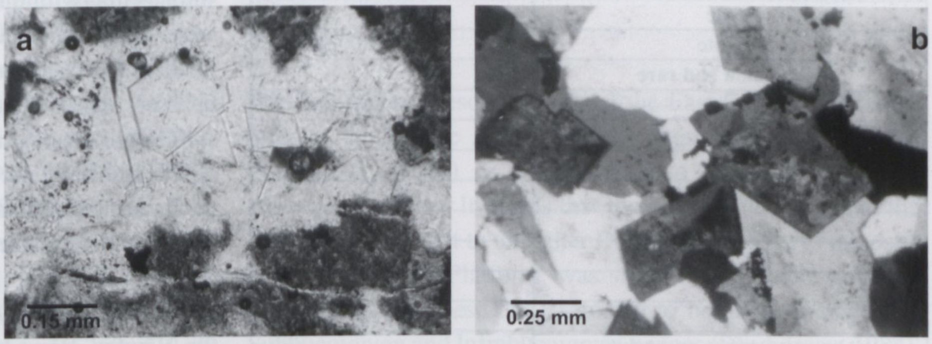

Fig. 9. Photomicrographs illustrating typical aspects of hydrothermal adularia in the epithermal ore deposits from Baia Mare district: a) vug-filling adularia and quartz in the veinlets from Fața Mare–Ilba mineralisations; b) adularia and quartz as gangue minerals in the gold-rich mineralisations of Băița–Nistru ore deposit.

1.2.5 Ore mineralogy

The epithermal ore deposits of the Baia Mare Neogene metallogenetic district display very rich and complex mineralogical assemblages. Tens of minerals were identified and described in these ore deposits (*e.g.* more than 90 mineral species only in the Baia Sprie ore deposit) and among them, 9 minerals from Baia Sprie, Herja, Cavnic and Dealul Crucii deposits were described for the first time in the world.

The mineralogical assemblages consist of native elements (gold, silver, copper, arsenic, sulphur), sulphides, sulphosalts, iron oxides and hydroxides, wolframite, silica (quartz and chalcedony), K-feldspar (adularia), clay minerals, carbonates and sulphates. All the main minerals found within the epithermal low-sulphidation systems (White & Hedenquist, 1995; Hedenquist *et al.*, 1996), were also identified in the Baia Mare district (Table 1).

The Pb, Zn and Cu sulphides, along with the pyrite, occur in all the ore deposits. The frequency and the abundance of

Table 1. Relative abundance of typical low-sulphidation epithermal ore and gangue minerals in Baia Mare district.

Ore and gangue minerals	
Typical for lowsulphidation epithermal deposits (Hedenquist *et al.*, 1996)	In the Baia Mare district epithermal deposits
Ubiquitous	
pyrite	+++
quartz	+++
Common	
sphalerite	+++
galena	+++
arsenopyrite	+++
chalcopyrite	++
tetrahedrite	++
native gold	++
electrum	+
pyrargyrite	+
tellurides	±
chalcedony	++
adularia	+++
illite	+++
calcite	+++
smectite	+++
Uncommon and rare	
stibnite	+
cinnabar	+
tennantite	±
enargite	–
covellite	+
selenides	–
barite	++
kaolinite	+++
Absent except as overprint	
pyrophyllite	±
alunite	–
diaspore	–

+++ = in all the ore deposits, abundant
++ = in all the ore deposits, variable
+ = in some of the ore deposits
± = a single occurrence
– = absent

these sulphides vary according to the ore-forming conditions and the features of each of the epithermal systems. The native gold was also reported in all the ore deposits, either as a free mineral or incorporated by sulphides such as pyrite, arsenopyrite, chalcopyrite, sphalerite, galena, *etc*. The native gold is the dominant mineral of the assemblages found in the Săsar–Dealul Crucii gold–silver metallogenetic field and it is frequent and abundant in the upper, gold-rich zones of the base metal–gold ore deposits such as Şuior, Cavnic, Băiuţ and Baia Sprie.

Overall, the Fe, Sn, Bi, W minerals occur in the earliest mineralogical assemblages and the Au, Ag, Sb and As minerals occur in the latest ones, respectively.

Some of the ore minerals are typical for a single ore deposit: *e.g.* the tellurides from the Nistru ore deposit, according to Stoicescu *et al.* (1967), the stibarsen from the Cavnic ore deposit, according to Mariaş (1999, 2005) and the lead sulphosalts as veenite and heteromorphite from the Herja ore deposit, according to Damian & Cook (1997).

Complex mineral assemblages, with specific parageneses and more generations of the same mineral occur in many ore deposits of the Baia Mare district due to the presence of the overlapped mineralising events and of the sequences of polyascendent mineralisations. In the Cavnic ore deposit, Mariaş (2005) has been identified three generations of sphalerite and chalcopyrite only in the mineral assemblages of the main mineralising event. A complex sequence of mineral deposition, was described by Damian (2003) in the Herja ore deposit (typical for the Herja–Băiuţ base metal epithermal system): pyrite – Fe-rich sphalerite + chalcopyrite – arsenopyrite + löllingite – pyrhotite – native gold (included in pyrite and sphalerite) – galena (with native gold included) + pyrite + sphalerite + chalcopyrite – freibergite – stibnite – marcasite + berthierite + jamesonite – bournonite – lead and silver sulphosalts (with quartz) – pyrite + marcasite + native gold + silver sulphosalts (with carbonate minerals).

It is worth to mention also some ore minerals, which are rare or show interesting features. Among them, the Bi sulphosalts associations occur in the cupriferous stages of the Nistru and Băiuţ ore deposits, the members of the aikinite–bismuthinite and lillianite homologous series were identified in the high temperature assemblages of the Nistru ore deposit (Damian & Cook, 1999) and the Se-bearing Bi sulphosalts, associated with chalcopyrite and native gold were described in the Văratec–Băiuţ base metal + copper ore deposit (Cook & Damian, 1997; Damian & Costin, 1999).

An interesting assemblage consisting of tungsten-bearing minerals (wolframite and scheelite) was noticed in the cupriferous + W mineralisation from the Principal vein in the Baia Sprie ore deposit by Superceanu (1957) and Manilici *et al.* (1965). There, Bailly *et al.* (2002) identified a clear zoning, from a nearly pure hübnerite (MnO) core, with many fluid inclusions, toward nearly pure ferberite (FeO) rims on some idiomorphic tabular crystals, up to 2 cm long of wolframite.

An outstanding occurrence of stibarsen has been described in the Cavnic ore deposit (Bolduţ mine, Iosif vein): large–size (30–40 cm), spheroidal and crustiform aggregates of stibarsen, sometimes with filaments of native gold, silver and arsenic and stibnite (Mariaş, 2005). Well known are the curved and ring-shaped jamesonite crystals from Herja ore deposit (Moţiu *et al.*, 1972; Ghiurcă & Moţiu, 1986; Udubaşa *et al.*, 1993; Cook & Damian, 1997). More recently, Mariaş (2005) described ring-shaped and tubular jamesonite crystals as inclusions in fine tabular barite crystals of the Cavnic ore deposit (Roata mine).

Some minerals were described in the Baia Mare metallogenetic district for the first time in the world. Andorite was initially described by Krenner (1892) in the Baia Sprie ore deposit, later on in the Dealul Crucii gold–silver ore deposit

(Koch, 1926) and more recently it was found in the Herja ore deposit (Damian, 1996, 2003). The Baia Sprie ore deposit is the type locality for dietrichite (Schröckinger, 1878), szmikite (Schröckinger, 1877), felsőbányaite (Kenngott, 1853) and klebelsbergite (Zsivny, 1929), which have not been found in any other occurrences of the district. Semseyite was described by Krenner (1881) in the same ore deposit, Baia Sprie, but the best occurrence, with radial aggregates of several cm-sized crystals, is the Herja ore deposit (Damian, 1996, 2003). The Herja and Dealul Crucii ore deposits are the type localities for fizélyite (Krenner & Loczka, 1925) and fülöppite (Fináły & Koch, 1929), respectively. Rhodochrosite is another mineral for the first time described, in the Cavnic ore deposit, by Hausmann (1813). After a long debate in the international mineralogical community, all of the nine minerals described for the first time in Baia Mare district are recorded by the IMA LIST as valid species. For further details on the history of these species see Papp (1994).

The complex mineralogical assemblages were attributed to the ore-forming fluids spanning very different ranges of temperature and salinity. An overall range of 150–320 °C is characteristic for the mineralisations of the Baia Mare district, as Borcoş *et al.* (1972, 1974), Manilici & Kalmar (1973), Pomârleanu & Petreuş (1968), Pomârleanu *et al.* (1985), Nedelcu & Pintea (1993), Damian (1996), Mariaş (1996), Bailly *et al.* (1998) and Grancea *et al.* (2002) reported about the homogenisation temperatures of the fluid inclusions from quartz, calcite, fluorite and sphalerite.

The cupriferous mineralisations of the base metal ore deposits were formed at higher temperatures: *e.g.* 250–320 °C in the Nistru Pb-Zn–Cu ore deposit (Borcoş *et al.*, 1974) and 265–340 °C in the Băiuţ Cu-Pb-Zn ore deposit (Manilici & Kalmar, 1973). Decreasing temperatures, from 315 °C and 324 °C respectively in the early mineralizing event, to ~200 °C in the late events, were reported in the Cavnic ore deposit by Grancea *et al.* (2002) and Mariaş (2005). The lower temperatures are typically determined for the gold–silver mineralisations (*e.g.* 160–220 °C in Borzaş gold-rich stockwork, according to Borcoş *et al.* (1972) and 170–210 °C in Săsar ore deposit, according to Bailly *et al.* (1998). Similar temperatures were determined for the gold-rich mineralisations occurring in the upper part of some base metal ore deposits (*e.g.* in the Baia Sprie ore deposit, 160–250 °C for the fluid inclusions in quartz and sphalerite from the veinlets of the Dealul Minei open pit, according to Grancea *et al.*, 2002).

The ore-forming fluids from the ores of the Baia Mare district had an overall higher salinity than those of the typical low-sulphidation epithermal ore deposits, covering the range from 1 to 21 wt% NaCl equiv. (*e.g.* 1–14 wt% NaCl equiv. in Cavnic ore deposit, according to Piantone *et al.*, 1999; 3.6–19.9 wt% NaCl equiv. in Baia Sprie ore deposit, according to Nedelcu & Pintea, 1993 and 5–15.2 wt% NaCl equiv. in Dealul Minei open pit, the upper part of the Baia Sprie ore deposit, according to Grancea *et al.*, 2002). Besides the salinity of the ore fluids, the main ore deposits of the Baia Mare district show highly variable homogenisation temperatures suggesting the complex evolution of the hydrothermal systems, mainly as open systems involving magmatic fluids mixed with meteoric waters and boiling processes.

The lead isotope compositions identified in the ore deposits of the Baia Mare district are well clustered within the radiogenic values: $^{206}Pb/^{204}Pb$ ratios range from 18.752 to 18.876, and $^{208}Pb/^{204}Pb$ ratios from 38.841 to 38.981 (Marcoux *et al.*, 2002). The similarity between isotopic compositions of the ore deposits and the volcanic rocks is in agreement with the genetic link between the volcanism and the epithermal activity, *i.e.* the common crustal-contaminated magmatic source (Kovacs, 2001; Marcoux *et al.*, 2002).

1.3 The Crystalline-Mesozoic Zone of the East Carpathians. A review

by Ioan Balintoni

1.3.1 Structure

The Crystalline-Mesozoic Zone of the East Carpathians, if we refer to the mobile Alpine belt, belongs to Median Dacides (Săndulescu, 1984) or, alternatively, to the eastern Getides (Balintoni, 1997a). It means that the continental margin of the Getic plate adjacent to the outer Dacic rift, in the area opposite to the Moldavian Platform, was sheared in order to generate several nappes. These are (from top to bottom): Bucovinian, Subbucovinian and Infrabucovinian nappes (Săndulescu, 1984). The Bucovinian Nappe supports in places the "Transylvanian nappes" (Sandulescu, 1984), or the Wildflysch Nappe and gravity gliding Klippen (Hoeck *et al.*, 2009), devoid of a crystalline basement. In turn, at least the Bucovinian and Subbucovinian nappes consist of several Variscan tectonic units, as follows (from top to bottom): Rarău Nappe, Putna Nappe, Pietrosu Bistriţei Nappe and Rodna Nappe (Balintoni, 1981, Săndulescu *et al.*, 1981; Balintoni *et al.*, 1983).

1.3.1.1 *Alpine tectonic units*

a) Bucovinian Nappe

The Bucovinian Nappe (the uppermost nappe of the Getides) preserves overlying its metamorphic basement, Mesozoic sedimentary cover on large areas, including Triassic, Jurassic and Early Cretaceous deposits (Săndulescu, 1984 and references therein). It is largely developed especially south of the town of Vatra Dornei.

b) Subbucovinian Nappe

The Subbucovinian Nappe crops out from below the Bucovinian Nappe in a series of tectonic windows, *e.g.* Tomeşti window in the southernmost part of the Crystalline-Mesozoic Zone, the windows in the basin of the Putna Valley and the large outcropping area northward of the town of Vatra Dornei, along the Bistrița River valley. Likewise, in front of the Bucovinian Nappe several "rabotage" outliers, belonging to the Subbucovinian Nappe, crop out. The Subbucovinian sedimentary series covering the metamorphic basement is thinner than the Bucovinian one, with many gaps and unconformities. It starts with Permian verrucano deposits and ends with Neocomian calcareous breccias and calcarenites.

c) Infrabucovinian tectonic units

The Infrabucovinian tectonic units are found in a series of tectonic windows as fragments without continuity. In Maramureș, they are floating on the Black Flysch Nappe or on the Ceahlau Nappe. In places, they are represented only by sedimentary series, devoid of a crystalline basement. The presence of several sedimentary facies groups points out a large territory, highly sheared. From inside to outside the Infrabucovinian Units sedimentary covers can be grouped according to the facies groups in more and more complete sequences from Jurassic to Permian. Outside the Maramureș Mts., the Infrabucovinian units crop out in the Rodna Mts., in the Rusaia, Vatra Dornei-Iacobeni and Arșița Barnarului windows. It is to note the Măgurele "rabotage" outlier in the frontal part of the Bucovinian Nappe, north of Sadova.

1.3.1.2 Variscan tectonic units

The basements of the Bucovinian and Subbucovinian Nappes include all the four mentioned Variscan tectonic units, that is Rarău, Putna, Pietrosu Bistriței and Rodna (Balintoni, 1981, 1997).

a) The Rodna Unit question

Rodna Unit has always been delimited in the base by an Alpine shear plane and therefore it probably constituted the autochtonous for the Variscan thrusts. Consequently, the Rodna Unit does not represent a Variscan nappe. When we refer to it, we have to consider this aspect because, in fact, there are only three true Variscan nappes: Rarău, Putna and Pietrosu Bistriței.

b) Extension of the Variscan nappes

The Putna and Pietrosu Bistriței nappes, although discontinuous, crop out in the Bucovinian and Subbucovinian Nappes. It means that they have had a double extension compared with these nappes. The Rarău Nappe is part of the basement of the Bucovinian and Subbucovinian nappes and it forms the whole basement of the Infrabucovinian Nappes. This fact could indicate an ample Variscan thrusting if we consider that the outcrop width of the Crystalline-Mesozoic Zone of the East Carpathians can exceed 30 km. The minimum distance of the tectonic transport for the Putna and Pietrosu Bistriței Nappes is of 60 km and that for the Rarău Nappe of more than 100 km. If we follow transversally the components of the Bucovinian and Subbucovinian nappes basement, we observe the predominance of the Rarău and Putna Variscan nappes in the eastern part and of the Rodna Nappe in the western part, quite clearly due to the western vergence of the Variscan shear planes.

1.3.2 The succinct features of the metamorphites in the Variscan tectonic units

Balintoni *et al.* (2009) described three pre-Alpine terranes in the basement of the East Carpathians: Bretila, Tulgheș and Rebra. The Bretila terrane is constituted from the Bretila metamorphic unit, Tulgheș from Tulgheș metamorphic unit and Rebra from Negrișoara and Rebra metamorphic units. The Variscan nappes consist of slices of these metamorphic units.

Rarău Nappe

In the Bucovinian and Subbucovinian Alpine nappes the Rarău Nappe contains slices of the Bretila metamorphic unit. In the Infrabucovinian Units of the Rodna Mts., transgressive on the Bretila terrane fragments are known the Rusaia, Repedea and Cimpoiasa epizonal sequences (H.H. Kräutner, 1988).

Putna Nappe

Different slices of the Tulgheș metamorphic unit are located in the basement of the two upper Alpine nappes.

Pietrosu Bistriței Nappe

It is formed by the Negrișoara metamorphic unit.

Rodna Unit

It includes fragments of the Rebra metamorphic unit.

The Bretila, Negrișoara and Rebra metamorphic units are mesozonal polymetamorphic sequences, Early Paleozoic in age (Pană *et al.*, 2002; Balintoni *et al.*, 2009). The Tulgheș metamorphic unit is also a polymetamorphic sequence of the same age, but variable metamorphosed in the greenschists facies.

1.3.2.1 Description of the metamorphic sequences

Bretila metamorphic unit

Lithostratigraphy. Bretila metamorphic unit (Fig. 10) was defined in 1938 by T. Kräutner as the autochthonous mesozone of the Eastern Carpathians. In 1968, H. Kräutner stressed out the lithostratigraphic correspondence of the Bretila Series with that of the Rarău gneisses. Bercia *et al.* (1971) included the following sequences in the Bretila Series: Bretila Series in the Bistrița and Rodna Mts; Rarău Gneisses Series in the Rarău and Haghimaș synclines; Novăț Series in the Vaser Basin; Pop Ivan mesozone; Belopotoc Series over the border.

This represents a decisive step in the knowledge of the similar features of successions belonging to this metamorphic unit in all the major outcropping places, excepting the Vatra

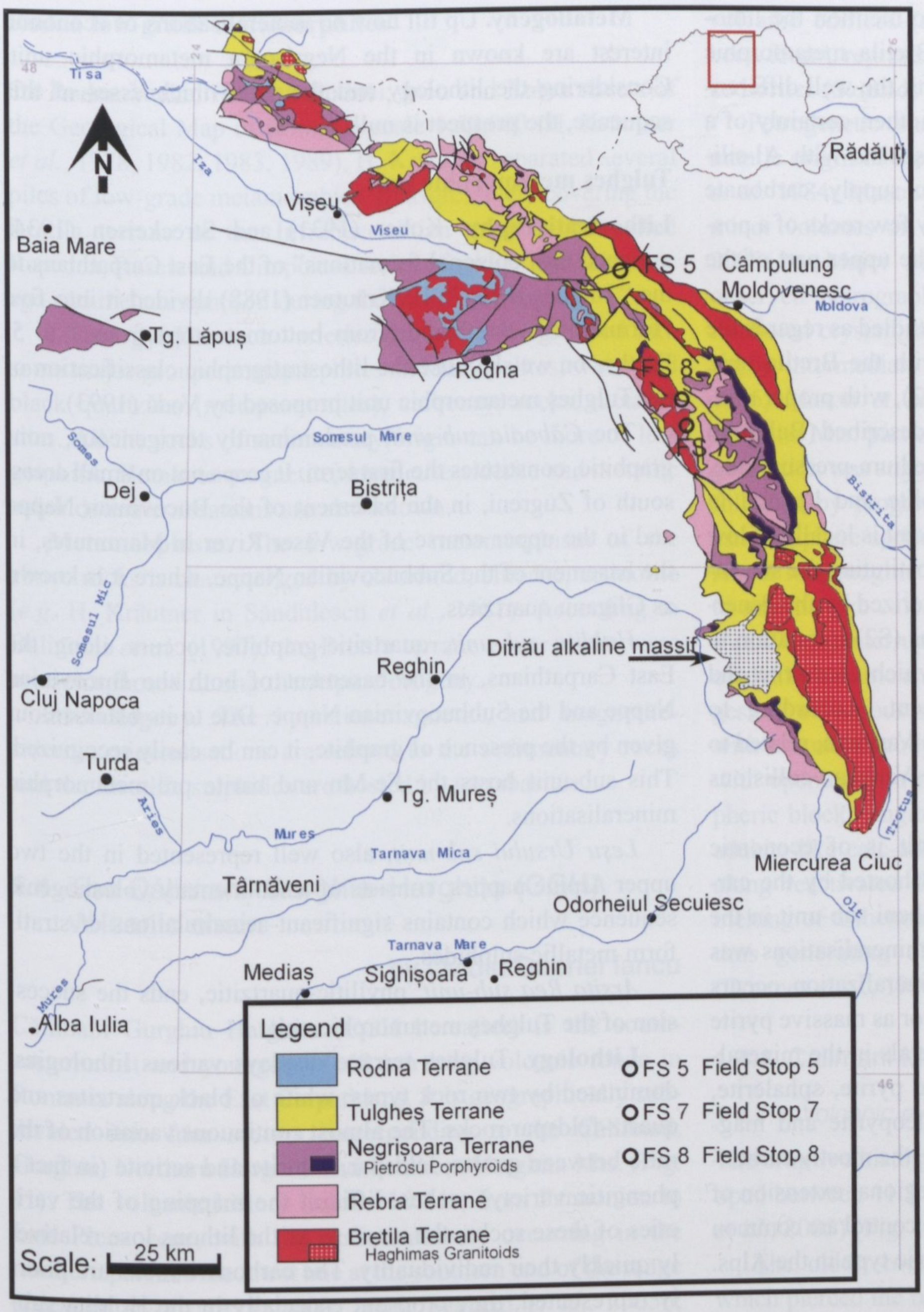

Fig. 10. Metamorphic sequences of the Eastern Carpathians (Rodna Terrane, Tulgheş Terrane, Negrişoara metamorphic unit, Rebra metamorphic unit and Bretila Terrane).

Dornei-Iacobeni mesozone, which was assigned to the Rebra Series. That confusion was cleared up by Balintoni in 1984.

Lithology. Although it is poorly divided in lithostratigraphic respect, the Bretila metamorphic unit is well-known and well-characterized from lithological point of view. The Infrabucovinian Nappes include: paragneiss, microcline gneiss, fine-grained white gneiss with leptinitic appearance alternating or not with amphibolite, augen gneiss, micaschist, porphyroid. In the Bucovinian Rarău sub-unit, beside micaschist, augen gneiss, paragneiss and amphibolite, a special rock suite – the Hăghimaş, and Mândra metagranitoids occurs as well. The carbonate rocks are practically missing.

Metamorphism. Bercia *et al.* (1971, 1976) and H. Kräutner (1988) mentioned an initial metamorphism in the almandine amphibolite facies, followed by a Variscan and Alpine retromorphism.

Metallogeny. The known metallogeny of the Bretila terrane is poor.

Rebra metamorphic unit

Lithostratigraphy. The Rebra metamorphic unit (H. Kräutner, 1968) (Fig. 10) was essentially described by H. Kräutner (1968, 1980, 1988) and Bercia *et al.* (1971, 1976). It was divided by H. Kräutner *et al.* (1982) from bottom to top, in the Izvorul Roşu, Voşlobeni and Ineu "formations".

The *Izvorul Roşu sub-unit* consists of paragneiss, interfingered with micaschist that can include staurolite, kyanite, sillimanite, as well as subordinated intercalations of carbonate rock and quartzite.

The *Voşlobeni sub-unit* is represented by a thick pile of carbonate rock with intercalations of paragneiss, white and black quartzite. The carbonate rocks can be laterally substituted also by the other rocks mentioned above. On large areas, at the top and the bottom of the sub-unit, amphibolites or thick amphibolitic gneisses can be found which, in the Rodna Mts. at Bâzdâga (the lower ones), contain pyrrhotite-chalcopyrite-magnetite mineralisations and, in the Bistriţa Mts (the upper ones), lenses of massive magnetite of relatively small sizes. Due to them, the Subbucovinian Rebra metamorphic unit can be traced in geophysical respect between Bistricioara and Zugreni, in the right side of the Bistriţa River. Also in the Rodna Mts, the carbonate portions of the Voşlobeni sub-unit, especially when they are related to quartzites and other terrigene lithons, host lead-zinc accumulations of industrial significance (Udubaşa *et al.*, 1981). Graphite occurs in carbonate rocks and there are zones, where the graphitic black quartzites are very well represented. Graphite is usually accompanied by metallic minerals.

The *Ineu sub-unit* consists especially of quartz micaschists with intercalations of thin lithons of limestone, dolomite, biotitic quartzite, amphibolite and microlitic gneiss, white and black quartzite.

Lithology. From the beginning it is to mention the lithologic contrast between the Rebra and Bretila metamorphic units. Thus, in the Rebra metamorphic unit the well differentiated, mature rocks, distinct one from another, certainly of a sedimentary origin, are prevailing: micaschists with Al-silicates, quartzite, sometimes with organic supply, carbonate rocks in thick piles, paragneisses, and only few rocks of a possible acid magmatogene origin occur at the upper part of the metamorphic unit.

Metamorphism. Rebra unit is better studied as regards the metamorphic evolution in comparison with the Bretila unit. Thus, two mesozonal events (M1) and (M2), with proper mineralogic and structural features have been described (Balintoni & Gheuca, 1977). The (M1) event is a medium-pressure one, characterized by the presence of staurolite and kyanite in micaschists and paragneisses. The (M2) event is locally of low pressure with andalusite and cordierite substituting the staurolite and kyanite. This event is also characterized by the generation of transposition axial-plane foliations (S2) in relation to which the thermal culmination, during which cordierite and andalusite grow statically, is subsequent. According to Balintoni *et al.* (2009), the second event is Variscan, related to exhumation of the Rebra terrane after the Variscan collisions and thrusts.

Metallogeny. Rebra metamorphic unit is of economic importance for the Pb-Zn mineralisations hosted by the carbonatic rocks of the Subbucovinian Voşlobeni sub-unit in the Rodna Mts. A synthesis paper on these mineralisations was published by Udubaşa *et al.* (1981). Mineralization occurs either disseminated in the carbonate rocks or as massive pyrite flattened lithons. The major metallic minerals in the mineralized parts of the carbonatic sequence are pyrite, sphalerite, galena and subordinately pyrrhotite, chalcopyrite and magnetite. According to the mentioned authors, the mostly carbonate environment, the ore mineralogy, the regional extension of the mineralized lithons and their stratigraphic control are common for all ores of Mississippi Valley and Triassic type in the Alps.

Negrişoara Metamorphic Unit

Lithology. This unit was delimited by Balintoni & Gheuca (1977) and consists of a mostly terrigeneous lower sequence similar to the Subbucovinian Ineu sub-unit and of a metadacitic upper layer (Balintoni & Neacşu, 1980), quite typical mesoscopically, the Pietrosu Bistriţei porphyroid gneiss.

Lithology. The Pinu lower sub-unit is represented by quartz-biotite paragneiss with intercalations of thin and discontinuous lithons of carbonate rock, amphibolite and microclinic white gneiss. The Pietrosu porphyroids might represent products of an intracrustal magmatic reservoir that is dacitic metaignimbrites.

Metamorphism. The metamorphic development of the Negrişoara metamorphic unit is similar, to a certain extent, to that of the Rebra metamorphic unit, minus the low-pressure mineral assemblage.

Metallogeny. Up till now no mineralisations of economic interest are known in the Negrişoara metamorphic unit. Considering the lithology and the small thicknesses of this sequence, the prospect is null.

Tulgheş metamorphic unit

Lithostratigraphy. Kober (1931) and Streckeisen (1934) assigned the "epizonal formations" of the East Carpathians to the "Tulgheş Series". H. Kräutner (1988) divided it into five "formations", numbered (from bottom to top) from 1 to 5. Further on we shall use the lithostratigraphic classification of the Tulgheş metamorphic unit proposed by Vodă (1993).

The *Căboaia sub-unit*, predominantly terrigeneous, non-graphitic, constitutes the first term. It crops out on small areas, south of Zugreni, in the basement of the Bucovinian Nappe and in the upper course of the Vaser River in Maramureş, in the basement of the Subbucovinian Nappe, where it is known as Gliganu quartzites.

Holdiţa sub-unit, quartzitic-graphitic, occurs along the East Carpathians, in the basement of both the Bucovinian Nappe and the Subbucovinian Nappe. Due to its black colour given by the presence of graphite, it can be easily recognized. This sub-unit hosts the Fe-Mn and barite pre-metamorphic mineralisations.

Leşu Ursului sub-unit, also well represented in the two upper Alpine nappes, consists of a sedimentary volcanogenic sequence which contains significant accumulations of stratiform metallic sulphides.

Arşiţa Rea sub-unit, phyllitic-quartzitic, ends the succession of the Tulgheş metamorphic unit.

Lithology. Tulgheş terrane displays various lithologies, dominated by two rock types: white or black quartzites and quartz-feldspar rocks. The almost continuous variation of the ratio between quartz, feldspar, chlorite and sericite (in fact a phengitic variety) makes difficult the mapping of the varieties of these rocks, the more so as the lithons lose relatively quickly their individuality. The carbonate rocks are poorly represented; they crop out especially in the Holdiţa sub-unit where a characteristic association is found: black quartzite, white quartzite, carbonate rocks, chloritic and feldspar green rocks which do not represent metabasites but sedimentary rocks whose origin was favored by the iron abundance. Metabasites, like the carbonate rocks, are scarce or absent.

Metamorphism. Tulgheş metamorphic unit is polymetamorphic. Data of Balintoni & Chiţimuş (1973) indicates the following stages of evolution: (1) the substitution of the detrital ilmenite by rutile I; (2) transposition of the ilmenite pseudomorphosis into S2 and recrystallization of rutile I into rutile II.

Metallogeny. The Tulgheş metamorphic unit is the major Mn producer in Romania and it represents a notable percentage from the output of Pb, Zn, Cu and pyrite, as well as of barite.

Rodna low-grade metamorphites

On Rodna Veche, Pietrosu Rodnei, Ineu and Rebra sheets of the Geological Map of Romania scale 1:50,000 (H. Kräutner *et al.*, 1978, 1982, 1983, 1989), H. Kräutner separated several piles of low-grade metamorphics, transgressively covering the Bretila terrane in the Infrabucovinian nappes and called Repedea, Rusaia and Cimpoiasa series of mid to late Paleozoic age and metamorphosed during the Variscan Orogeny.

Lithology. The rock varieties can be easily grouped into some major groups: metapsephites and metapelites, white and black quartzites (metapsammites), carbonate rocks, metabasites. All the rocks of sedimentary origin can be more or less graphitic. Hematite-magnetite, magnetite-siderite and metallic sulphide mineralisations are also known.

Metamorphism. The low-grade metamorphism of the above rocks is characterized by chloritoid, chlorite, actinolite (*e.g.* H. Kräutner in Săndulescu *et al.*, 1981). According to Balintoni *et al.* (1997), the Bretila terrane cover rocks were metamorphosed during the Alpine orogeny.

Metallogeny. The hematite-magnetite and magnetite-sideritic mineralisations are related to the sedimentary rocks and the metallic sulphides are hosted by metabasites.

1.4 The Călimani–Gurghiu–Harghita (CGH) volcanic chain

by Ovidiu Gabriel Iancu

Călimani–Gurghiu–Harghita (CGH hereafter) is the south-easternmost and youngest, ~160 km long volcanic range in Romania along the East Carpathians. It is geographically subdivided into four sectors corresponding to the Călimani, Gurghiu, Northern Harghita and Southern Harghita Mts. (Fig. 11). The volcanic history lasted ~10 Ma, from Pannonian to Late Pleistocene, with the earliest activity occurring in the northern part and the latest one at the southern end of the range (Pécskay *et al.*, 1995, 2000, 2006; Seghedi *et al.*, 2005b; Moriya *et al.*, 1996; Vinkler *et al.*, 2007). Most of CGH lies at the boundary between two major structural units, the Eastern Carpathians and the Transylvanian Basin, being underlined by a ~30 km thick crust (Dérerová *et al.*, 2006).

The volcanic structure and morphology of the CGH chain is dominated by an axial row of closely spaced, adjoining or partially overlapping andesitic composite edifices with largely developed and merged peripheral volcaniclastic aprons that form a continuous fringe especially along the western side of the chain (Szakács & Seghedi, 1995).

Rock types mostly range from basaltic andesites to dacites, with porphyritic two pyroxene andesites and pyroxene and amphibole andesites as the most common petrotypes. Aphyric andesites and dacites, as well as lavas containing biotite are less frequent. Garnet-bearing andesites are found in rare occurrences in the Călimani Mts. In the central parts of the volcanic edifices (craters or calderas) intrusive rocks have been found, represented by various types of diorites and monzodiorites (Szakács & Seghedi, 1995).

Petrogenetic studies pointed out the subduction-related mantle origin of the magmas in CGH (Rădulescu, 1973; Peltz *et al.* 1984; Mason *et al.*, 1995, 1996) with the exception of minor volumes of crust-derived rocks (Seghedi *et al.*, 1995, 2005a,b). Major petrogenetic processes responsible for the observed petrographical and petrochemical features include fractional crystallization, crustal assimilation and magma mixing in intermediary crustal magma chambers (Seghedi *et al.*, 1995, Mason *et al.*, 1995, 1996). For the Călimani–North Harghita Mts. part of the range along-arc calc-alkaline magma generation was suggested to be related to an oblique subduction followed by progressive break-off of the subducted slab and asthenosphere uprise (Mason *et al.*, 1998; Seghedi *et al.*, 1998). At ~3 Ma, magma compositions changed in South Harghita to adakite-like calc-alkaline and continued until recent times (< 0.03 Ma) interrupted at 1.6–1.2 Ma by simultaneous eruption of alkalic basaltic and shoshonitic varieties in nearby areas, suggestive of various sources and melting mechanism associated with two main geodynamic events: (a) slab-pull and steepening, with opening of a tear-window in the vertical Vrancea lithospheric block hanging into the asthenospheric mantle (forming adakite-like calc-alkaline magmas) and (b) inversion tectonics along reactivated fault systems that allowed decompression melting of asthenospheric (OIB-like) and lithospheric sources, thus generating alkalic basaltic and shoshonitic magmas (Downes *et al.*, 1995; Seghedi *et al.*, 2004, 2005a, 2010).

1.4.1 Călimani Mountains

1.4.1.1 Volcanic evolution

The eruptive history of the Călimani volcanic structure developed between 11.3 and 6.7 Ma (Pécskay *et al.*, 1995; Seghedi *et al.*, 2005) (Fig. 12).

The oldest rocks belong to exhumed shallow intrusions, which pierced the basement between 11.3–9.4 Ma ago and represent the south-eastward extension of the "Subvolcanic zone" (Pécskay *et al.*, 2009). The oldest stratovolcano was centered on the area occupied by the presently recognizable main volcanic edifices, Rusca–Tihu and Călimani Caldera and grew very large (~300 km^3), generating a large-volume (26 km^3) debris avalanche deposit to the west and southwest resulted from a large-scale edifice failure event (Szakács & Seghedi, 1996, 2000). Debris avalanche blocks dated at 10.2–7.8 Ma, suggest that the edifice failure event occurred at 8.0 ± 0.5 Ma. Volcanic centres generating the Drăgoiasa Formation (9.3–8.4 Ma), the Budacu Formation (9.0–8.5 Ma), the Lomaş Formation (8.6 Ma), a number of peripheral domes (8.7–7.1 Ma) and the Sărmaş basalts (8.5–8.3 Ma) were also active before the occurrence of the edifice failure event (Peltz *et al.*, 1987a; Seghedi *et al.*, 2005).

Volcanic activity continued at the Rusca-Tihu volcano between 8.0–6.9 Ma, generating the "Rusca-Tihu Volcaniclastic

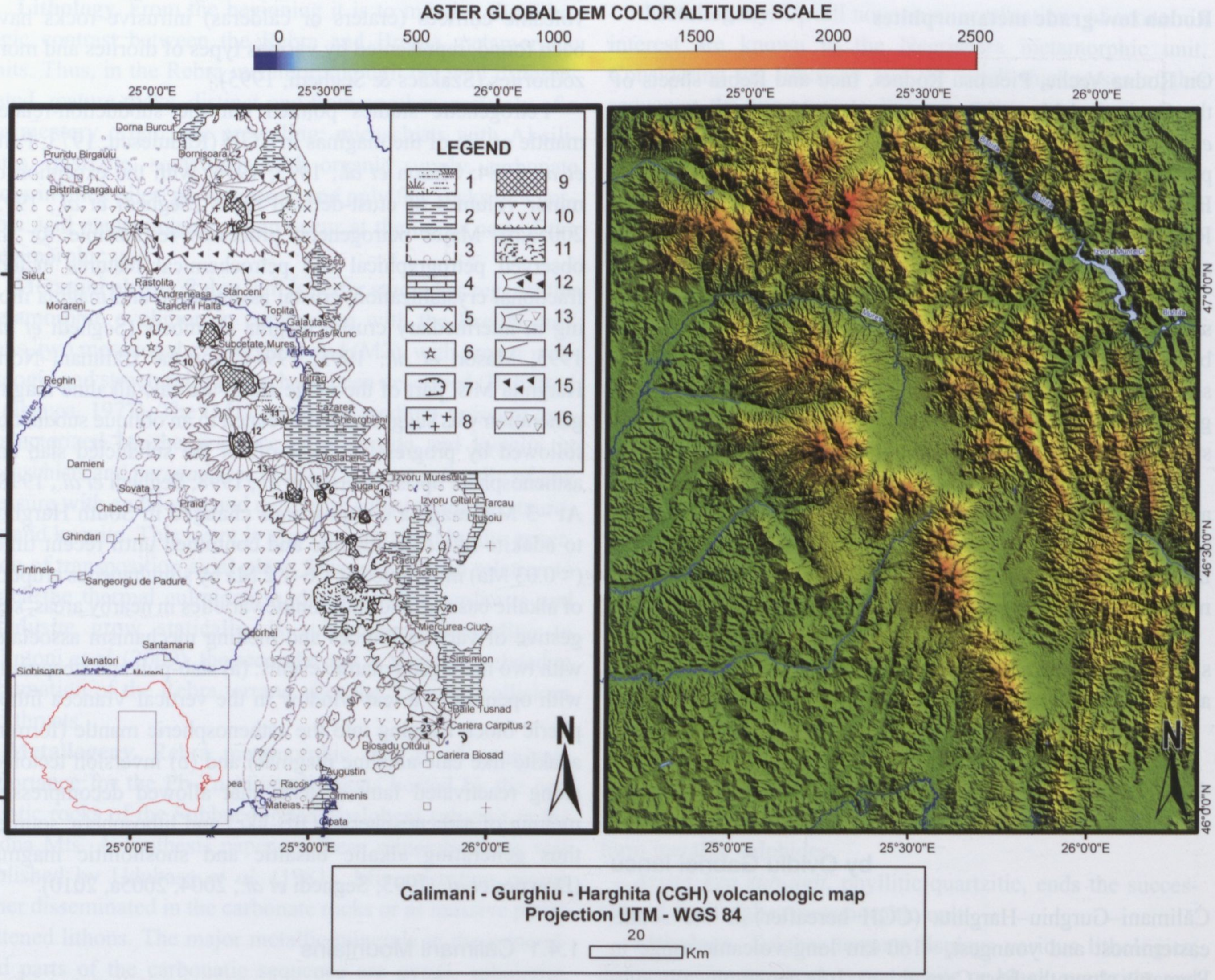

Fig. 11. Volcanological map of Călimani–Gurghiu–Harghita Mountains (modified after Szakács & Seghedi, 1995): 1 – Quaternary swamp or lake deposits; 2 – Tertiary postvolcanic and synvolcanic sediments; 3 – Tertiary prevolcanic molasse sediments of Transylvanian basin; 4 – Late Paleozoic-Cretaceous sediments of East Carpathians; 5 – Precambrian-Paleozoic metamorphic and plutonic rocks of Crystalline-Mesozoic Zone of East Carpathians; 6 – Neck; 7 – Crater, caldera-like depressions, and/ or Collapse calderas (caldera fault); 8 – Porphyritic intrusive rocks; 9 – Fine porphyritic intrusive rock or volcanic core complexes; 10 – Extrusive domes; 11 – Lava flows; 12 – Pyroclastic cone; 13 – Stratovolcanic cone; 14 – Effusive cone; 15 – Coarse pyroclastic rocks, proximal facies; 16 – Mud flow, debris avalanche, debris flow and ephemeral stream epiclastic volcanic rocks.

Volcanic edifices and areas: ***Călimani Mts.***: 1 – Drăgoiasa; 2 – Lucaciul; 3 – Tamaul; 4 – Rusca-Tihu; 5 – Moldovanul; 6 – Călimani; 7 – South Călimani Vocanic field; ***Gurghiu Mts.***: 8 – Jirca; 9 – Obîrşia; 10 – Fâncel-Lapuşna; 11 – Bacta; 12 – Seaca Tătarca; 13 – Borzonţ; 14 – Şumuleu; 15 – Ciumani-Fierastraie; ***North Harghita Mts.***: 16 – Răchitiş; 17 – Ostoroş; 18 – Ivo-Cocoizaş; 19 – Vârghiş; ***South Harghita Mts.***: 20 – Şumuleu Ciuc; 21 – Luci-Lazu; 22 – Cucu; 23 – Pilişca; 24 – Ciomadul; 25 – Bicsad-Malnaş volcanic field.

Formation" (Szakács & Seghedi, 1996). Postcaldera evolution of the volcanic structure includes three major phases (Seghedi, 1987): (1) intracaldera eruptions giving rise to andesitic lava flows and a stratocone (Negoiul Românesc), (2) resurgent intrusion of a large shallow monzodioritic body, (3) extrusion of several small-volume dacitic lava domes on the caldera rim and on the southern flank of the volcanic edifice. Pre-caldera and post-caldera stages were dated at 7.5–6.7 Ma, with an inferred caldera formation event at 7.1 ± 0.5 Ma (Seghedi *et al.*, 2005). Monzodioritic-dioritic intrusive bodies in the central part of the caldera show ages between 8.8–7.3 Ma, implying several episodes of intrusions. The Călimani caldera with its actual summit elevation of ~2000 m a.s.l., and ~8 km in diameter is the most outstanding volcanic feature of the whole CGH (Fig. 13). Its north-north-westward-open amphitheatre is assumed to be a result of downward tilting of the intracaldera block starting from a NE–SW oriented hinge, in a trap-door caldera model (Seghedi, 1995). Volcanic rocks in the central intracaldera area have undergone extensive hydrothermal alteration processes (Teodoru & Teodoru, 1966, Stanciu & Medeşan, 1971, Seghedi *et al.*, 1985).

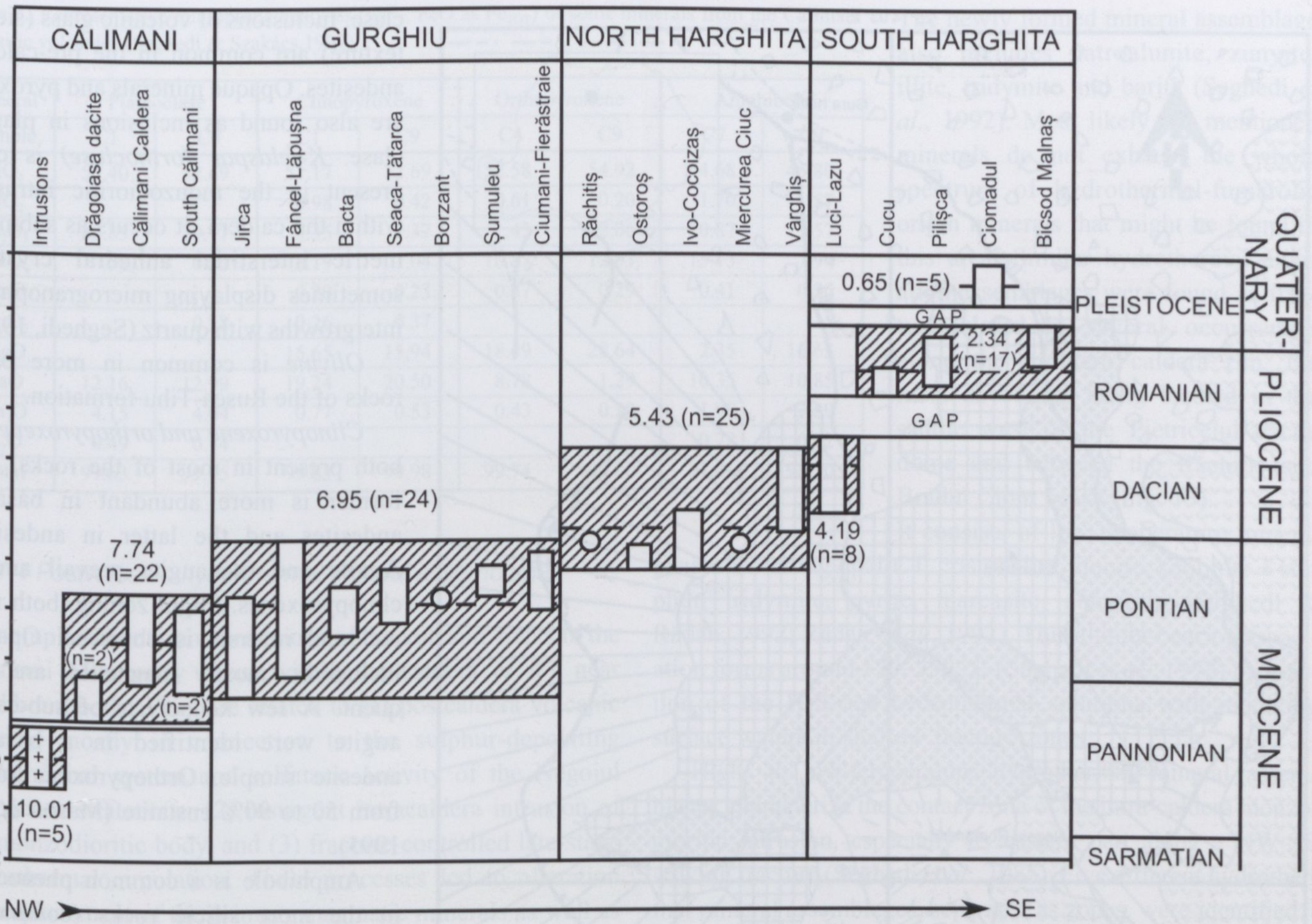

Fig. 12. Evolution of the volcanism along the Călimani–Gurghiu–Harghita chain as resulted from K-Ar data (Seghedi *et al.*, 2005b).

1.4.1.2 Petrological summary

Medium-K andesites prevail in the Călimani Mts., as in the whole CGH, but rock types range from basalt to rhyodacite. Low-K (<1 wt% K^2O) dacites are rarely found in the southern half of the area. The volcanic rocks are typically porphyritic with microcrystalline or glassy groundmass. Afanitic andesites are characteristically present in the north-western Călimani area. Cognate xenoliths are widespread, commonly including orthopyroxene, amphibole, feldspar and opaque minerals. Upper crustal xenoliths displaying lithologies of the local pre-volcanic basement are also frequent.

The main petrogenetic processes responsible for the formation of the Călimani volcanics are documented by major and trace element (including REE) as well as isotope geochemistry (Peltz *et al.*, 1974, 1987b; Seghedi *et al.*, 1995, 2005; Mason *et al.*, 1995, 1996). They can be summarised as follows:

– mantle source with obvious subduction signature of magmas for most of the Călimani volcanics, excepting for the earliest Drăgoiasa dacites for which a crustal source is suggested by Seghedi *et al.* (1995, 2005a, b); Source variability is characteristic for the early volcanic activity (Seghedi *et al.*, 2005a, b);
– ~10–15% partial melting of a mantle source material already metasomatized by subduction components (Seghedi *et al.*, 1995);
– fractional crystallisation was important in the generation of different magma series at lower to shallow crustal depths, where plagioclase was the main crystallizing phase, along with pyroxene, amphibole and Fe-Ti oxides, leading to magma diversification;
– crustal assimilation affected most of the analyzed samples to some degree through assimilation-fractional-crystallisation (AFC) processes that suggest a consumption of 5–35 % upper crustal material (Mason *et al.*, 1996). Isotopic enrichment of the most basic rocks suggests that contamination processes affected the source of most parental magmas, excepting those of the Lomaș Formation. The youngest volcanic rocks represented by the Călimani Caldera structure were derived from magmas of lower degree of partial melting largely affected by assimilation processes.
– magma mixing was pointed out by the presence of disequilibrium mineral assemblages in the small-volume post-caldera extrusive dacite domes (Seghedi, 1987; Nițoi, 1987).

Clinopyroxene-orthopyroxene geothermometry indicates crystallisation temperatures in the range 860–1150 °C for

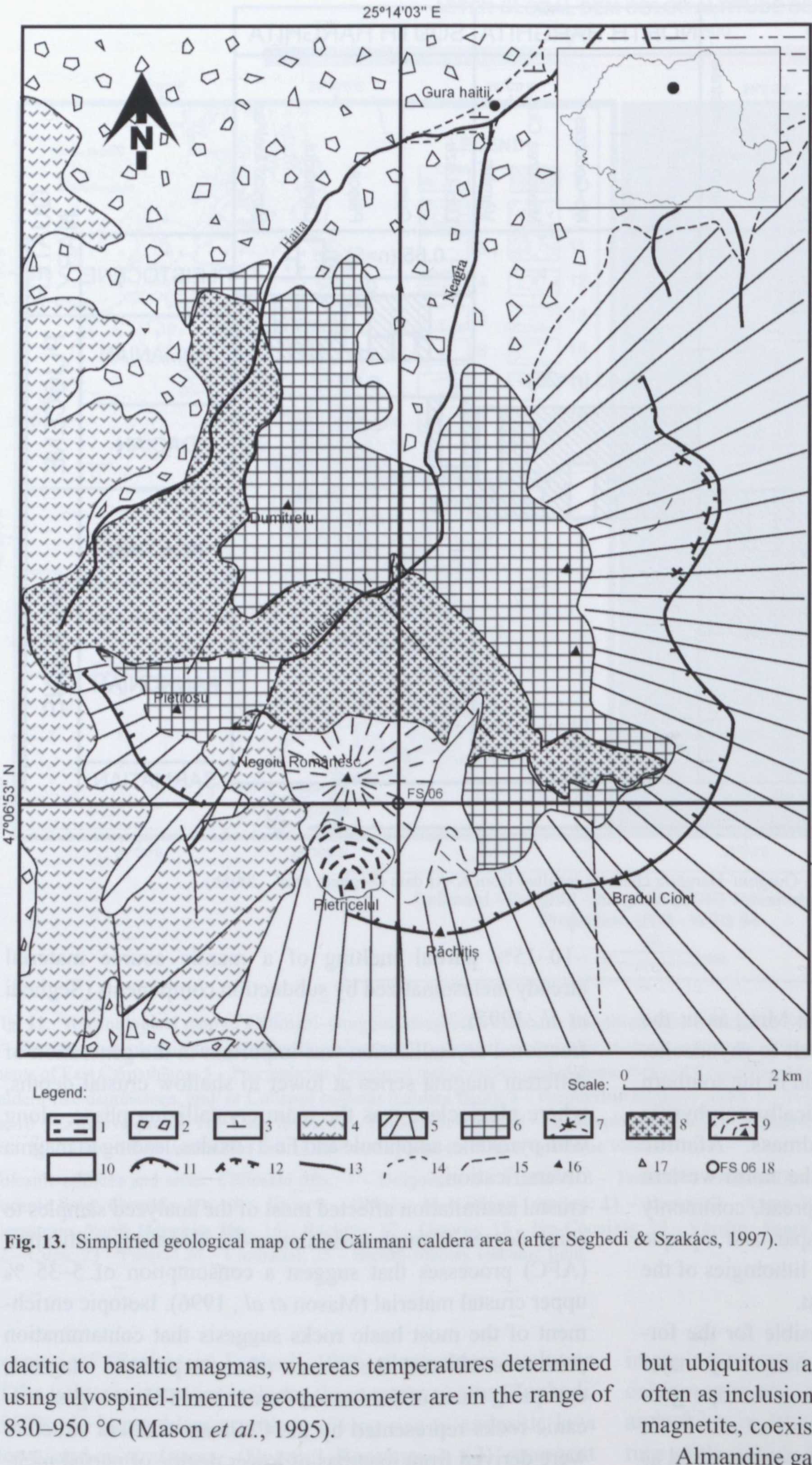

Fig. 13. Simplified geological map of the Călimani caldera area (after Seghedi & Szakács, 1997).

dacitic to basaltic magmas, whereas temperatures determined using ulvospinel-ilmenite geothermometer are in the range of 830–950 °C (Mason *et al.*, 1995).

1.4.1.3 Mineralogy and mineral chemistry of volcanic rocks

Plagioclase is the most common phenocryst phase occurring in all rock types. It displays a wide range of compositions from oligoclase to bytownite (An_{23-90}). Oscillatory zoning commonly develops in bands surrounding a more homogenous core in phenocrysts. Rim composition is typically more sodic than that of the core, and is similar to microlithic plagioclase. Inclusions of volcanic glass (sieve-texture) are common in the pre-caldera andesites. Opaque minerals and pyroxene are also found as inclusions in plagioclase. *K-feldspar (orthoclase)* is only present in the monzodioritic intrusion within the caldera. It occurs as submillimetric interstitial anhedral crystals, sometimes displaying micrographophyric intergrowths with quartz (Seghedi, 1982).

Olivine is common in more basic rocks of the Rusca-Tihu formation.

Clinopyroxene and orthopyroxene are both present in most of the rocks. The former is more abundant in basaltic andesites and the latter in andesites. Augite and titanaugite prevail among clinopyroxenes. Slight zoning, both normal and reverse, is observed. Opaque inclusions, mostly magnetite, are frequent. A few xenocrysts of sub-calcic augite were identified in a basaltic andesite sample. Orthopyroxene range from 50 to 90% enstatite (Mason *et al.*, 1995).

Amphibole is a common phenocryst in the more silicic rocks (commonly those with SiO_2>59%). Rim opacitisation of amphibole is frequent, as well as resorption or total replacement by plagioclase, pyroxene and opaques. Biotite is present in some early dacites in the eastern Călimani (Drăgoiasa dacite), as well as in the late-stage post-caldera dacites domes.

Quartz is recorded as a late-stage interstitial phase in the monzodioritic intrusive body, as well as a mineral phase interpreted as phenocrysts (Seghedi, 1982) or xenocrysts (Nițoi, 1987) in the Pietricelul dacite dome showing the obvious evidence of magma mixing.

The opaque minerals are accessory but ubiquitous as groundmass phase or microphenocrysts, often as inclusions in phenocryst phases. Titanomagnetite and magnetite, coexists with ilmenite in most rock types.

Almandine garnet was found as phenocrysts in a few small amphibole andesite intrusive domes located in the north-western and eastern parts of the Călimani Mts. Garnet inclusions in biotite have been also reported in the Drăgoiasa dacite (Nițoi, 1986).

Representative microprobe analyses for plagioclase, clino- and orthopyroxene, and amphibole in Călimani andesitic volcanics, according to Mason *et al.* (1995), are given in Table 2.

Table 2. Representative microprobe analyses (wt%; FeO as Fe_{TOT}) of some minerals from the Călimani andesitic volcanics (Seghedi & Szakács,1997).

Mineral	Plagioclase		Clinopyroxene		Orthopyroxene		Amphibole	
Sample	C1	C7	C1	C9	C4	C9	C7	C9
SiO_2	53.40	52.69	51.17	52.69	52.58	54.92	44.68	45.80
TiO_2			0.98	0.42	0.61	0.20	1.70	1.87
Al_2O_3	28.85	29.77	3.35	2.37	1.43	2.06	10.87	11.57
FeO	0.58	0.32	8.19	7.04	16.85	12.03	15.13	7.94
MnO			0.20	0.23	0.57	0.29	0.41	0.25
Cr_2O_3		0.28	0.26	0.37				
MgO			15.65	15.94	18.49	28.64	2.35	16.65
CaO	12.16	12.99	19.24	20.50	8.78	1.29	10.35	10.85
Na_2O	4.15	4.04	0.77	0.53	0.43	0.20	1.90	2.89
K_2O	0.49	0.14					0.22	0.22
Total	99.63	99.95	99.83	99.98	99.74	100.00	97.61	98.20

1.4.1.4 Postvolcanic hydrothermal mineral assemblages

Post-emplacement transformations of the volcanic rocks in the Călimani Mts partly occur within the caldera or it's near neighbourhoods. They are related to (1) postcaldera volcanic activity, mostly in connection to the sulphur-depositing hydrothermal system and solfataric activity of the Negoiul Românesc stratocone, (2) resurgent intracaldera intrusion of the monzodioritic body, and (3) fracture-controlled late-stage hydrothermal circulation. These processes led to alteration and replacement of the primary magmatic minerals as well as infilling of cavities and vein fractures with assemblages of new lower temperature and lower pressure minerals.

Low-temperature hydrothermal and solfataric activity accompanied sulphur deposition in the intracaldera area, closely related to the Negoiul Românesc postcaldera stratocone (Seghedi, 1987). Formerly, Balintoni (1970) assigned these processes to the moment of extrusion of post-caldera dacites domes. According to this author, hydrothermal transformations, such as formation of secondary quartzites and alunitisation, that accompanied sulphur deposition, have overprinted an earlier hydrothermally altered background (propilitisation, chloritisation). Detailed mineralogic and chemical studies by Stanciu & Medeşan (1971a, b) established the hydrothermal mineral assemblages accompanying genesis of the sulphur deposit. Alteration zonation, from outside to inside with respect the sulphur mineralisation, was observed as follows: weak alteration zone – chlorite zone – clay-mineral zone – siliceous zone. The mineral assemblages identified in the clay-mineral and siliceous zones are: (1) montmorillonite (smectite), kaolinite, dickite, gypsum, alunite, quartz (cristobalite in the clay-mineral zone), and (2) kaolinite, alunite, quartz (cristobalite and opal in the siliceous zone). Sulphur and iron sulphides (pyrite, marcasite, melnicovite) and their oxidized products (goethite, in the shallow part) have been impregnated the spongy siliceous matrix, resulted by prior acid leaching processes. During deposition of the replacement-type sulphur ore Ph varied from acid to slightly alkaline.

The newly formed mineral assemblage also includes natroalunite, zunyite, illite, tridymite and barite (Seghedi *et al.*, 1992). Most likely the mentioned minerals do not exhaust the whole spectrum of hydrothermal-fumarolic origin minerals that might be found in this area. Similar hydrothermal alteration assemblages were found as fracture-related in several occurrences along the southern caldera rim, the most developed being located in the saddle west of the Pietricelul dacite dome and between the Răchiţiş and Bradul Ciont peaks (Fig. 13).

It consists of low-temperature mineral phases including opal-CT, cristobalite, alunite, kaolinite ± sulphur, tridymite, pyrite, marcasite, anhydrite (Seghedi & Rădan, 1992; Rădan *et al.*, 1992). This alunite-bearing association forms around 120–250 °C (Seghedi *et al.*, 1992) by reaction of the H_2S-rich hydrothermal solutions with oxidizing surface waters in shallow fracture zones.

High- to low-temperature hydrothermal mineral assemblages characterize the contact zone of the intra-caldera monzodioritic intrusion, especially its eastern part along a NW-SE striking fracture (Seghedi *et al.*, 1985). Five different hydrothermal mineral assemblages, separated as zones, were identified:

(i) Albite zone presents plagioclase albitization and, in places, epidote formation;

(ii) Biotite zone, with the newly-formed biotite replacing mafic minerals and plagioclase or filling veinlets in association with quartz and K-feldspar.

(iii) Actinolite zone, with hydrothermal amphibole filling veins, veinlets and cavities, or forming impregnations, associated with epidote, quartz, albite, biotite, magnetite, pyrite, seldom calcite and K-feldspar;

(iv) Argillic zone, represented by illite-quartz, illite-montmorillonite (smectite)-kaolinite-quartz, or montmorillonite (smectite)-illite-quartz that often overprints the older assemblages.

(v) Quartz-sericite-tourmaline (schorlite type) zone, affecting both monzodioritic rocks including their thermal-metasomatic contact zone, and the surrounding andesitic rocks near the contact. Illite is also part of the association.

Zeolites were found up to one km far from the main hydrothermal halo of the intrusion (Seghedi, 1982). The zeolite association occurs as vein or cavity fillings in the host volcanic rocks (andesite lavas and volcaniclastic deposits). It includes laumontite, chabazite and epistilbite in association with quartz, calcite, dolomite, prehnite, pyrite and hematite. This mineral assemblage together with fluid inclusion data indicate formation conditions in the range T = 180–260 °C and P = 1–2 kbar (Seghedi & Pomârleanu, 1983).

1.5 The Ditrău Alkaline Massif

by Emil Constantinescu, Nicolae Anastasiu & Ovidiu Gabriel Iancu

1.5.1 Location, size, shape

The Mesozoic Ditrău Alkaline Massif (DAM), unique in Romania by size and petrographical variety, is emplaced within the metamorphic basement rocks at the interior of the East Carpathians. The DAM is an intermediate size massif (about 800 km^2) and exhibits an eccentric ring structure in which the more basic rocks tend to lie to the west, with an arcuate zone of syenitic rocks extending from the far north to the south-east, and a large area dominated by nepheline syenite on the eastern side (Fig. 14).

1.5.2 Geological location, age, tectonic setting

The DAM is considered to represent an intrusion body with a internal zonal structure, which was emplaced into pre-Alpine metamorphic rocks of the Bucovinian nappe complex close the Neogene-Quaternary volcanic arc of the Călimani–Gurghiu–Harghita Mountain chain (Ianovici, 1938; Kräutner & Bindea, 1998). The massif lies at the inner border of Mesozoic crystalline zone, within Tulgheş Group (Tulgheş Terrane according to Balintoni *et al.*, 2009). (see the introductory chapter).

The DAM formed during the Variscan orogeny. The precise U-Pb zircon age of 229.6±1.5–1.7 Ma determined by Pană *et al.* (2000) for the Ditrău syenite matches within error the hornblende 40Ar/39Ar dates obtained by Dallmeyer *et al.* (1997) from the diorite complex and hints to a relative short magmatic evolution of the DAM, within the Ladinian time (Mid-Triassic).

The alkaline massif of Ditrău has an intrusive character and its trend of enrootment has been proved by petrologic and geophysical arguments, too. It constitutes a multistage magmatic intrusion in a high level of the Earth's crust (Constantinescu & Anastasiu, 2004).

Parts o the DAM are unconformably overlain by andesitic pyroclastics with some interbedded basalt-andesite lava flows from the Neogene Harghita–Călimani and by Pliocene to Pleistocene lignite-bearing lacustrine deposits of the Jolotca basin (Rădulescu *et al.*, 1973). The intrusion developed a contact aureole against the country rocks, with hornfels containing cordierite, sillimanite, corundum, spinel and alkali amphibole (Streckeisen & Hunziker, 1974; Jakab, 1998; Hârtopanu *et al.*, 2000).

1.5.3 Short research history

Since its discovery by Herbich in 1859 (see Herbich, 1873) the massif has been the subject of many investigations. However, because of its structural complexity and wide petrographic variety, the petrogenesis is still not completely understood, and different studies led to different petrologic interpretations. Streckeisen (1960) explained the genesis of the massif by an origin through magmatic differentiation of an alkali syenite parental magma. Streckeisen & Hunziker (1974) presented a chronology of the magmatic events, suggesting early intrusion of the gabbros and diorites, followed by the syenites, nepheline syenites and granites culminating with emplacement of lamprophyric dykes, although without discussing the source of the magmas. Anastasiu & Constantinescu (1982) considered a magmatic derivation with two principal rock suites, one generated from a mantle-derived basic magma, and the other from a felsic alkaline magma formed through partial melting of crustal rocks with low silica content.

Based on detailed geochemical data, according to Dallmeyer *et al.* (1997), the intrusion of the Ditrău Alkaline Massif was associated with mantle-plume activity which predated Jurassic rifting within the Eastern Carpathian Orogen. On the basis of K-Ar and $^{39}Ar/^{40}Ar$ data Kräutner & Bindea (1998) dated the DAM emplacement. Pană *et al.* (2000) performed a precise U-Pb zircon dating of the syenite phase from the Ditrău Massif. Morogan *et al.* (2000) suggested that the whole complex have originated from basanitic magmas with OIB- character, generated by low degrees of melting of asthenospheric garnet lherzolite. However, the general dominance of amphibole among the ferromagnesian minerals points to the relatively hydrous nature of the Ditrău magmas and leads to the speculation that the primitive melts may have been modified by passage through hydrated (possibly amphibole-bearing) lithospheric rocks.

1.5.4 Petrography, petrology, geochemistry

The center of the Ditrău Alkaline Massif was formed by nepheline syenite, which is surrounded by syenite and monzonite. North-western and north-eastern marginal sectors are composed of hornblende gabbro/hornblendite, alkali diorite, monzodiorites, monzosyenites and alkali granite. Small discrete ultramafic bodies (kaersutite-bearing peridotite, olivine pyroxenite and hornblendite) and alkali gabbros occur in the Jolotca area. The later are also known from drill-cores in the Ditrău *s.s.* area (Morogan *et al.*, 2000). Hornblende gabbro/hornblendite and diorite represent the earliest intrusive phase, and are embedded within younger syenite and granite (Dallmeyer *et al.*, 1997; Morogan *et al.*, 2000). All these rocks are cut by late-stage dykes with a large variety of compositions including tinguaite, phonolite, nepheline syenite, microsyenite, and aplite, and later lamprophyre (Streckeisen 1952, 1954; Codarcea *et al.* 1958; Streckeisen & Hunziker, 1974; Anastasiu & Constantinescu, 1984; Anastasiu *et al.*, 1994). The dykes rarely exceed one metre in width and have multiple orientations (Morogan *et al.*, 2000). Streckeisen (1952, 1954, 1960) used the comprehensive term 'Ditro essexites' for the whole heterogeneous mesocratic suite of rocks from the Güdücz complex (Fig. 14), including gabbros, diorites,

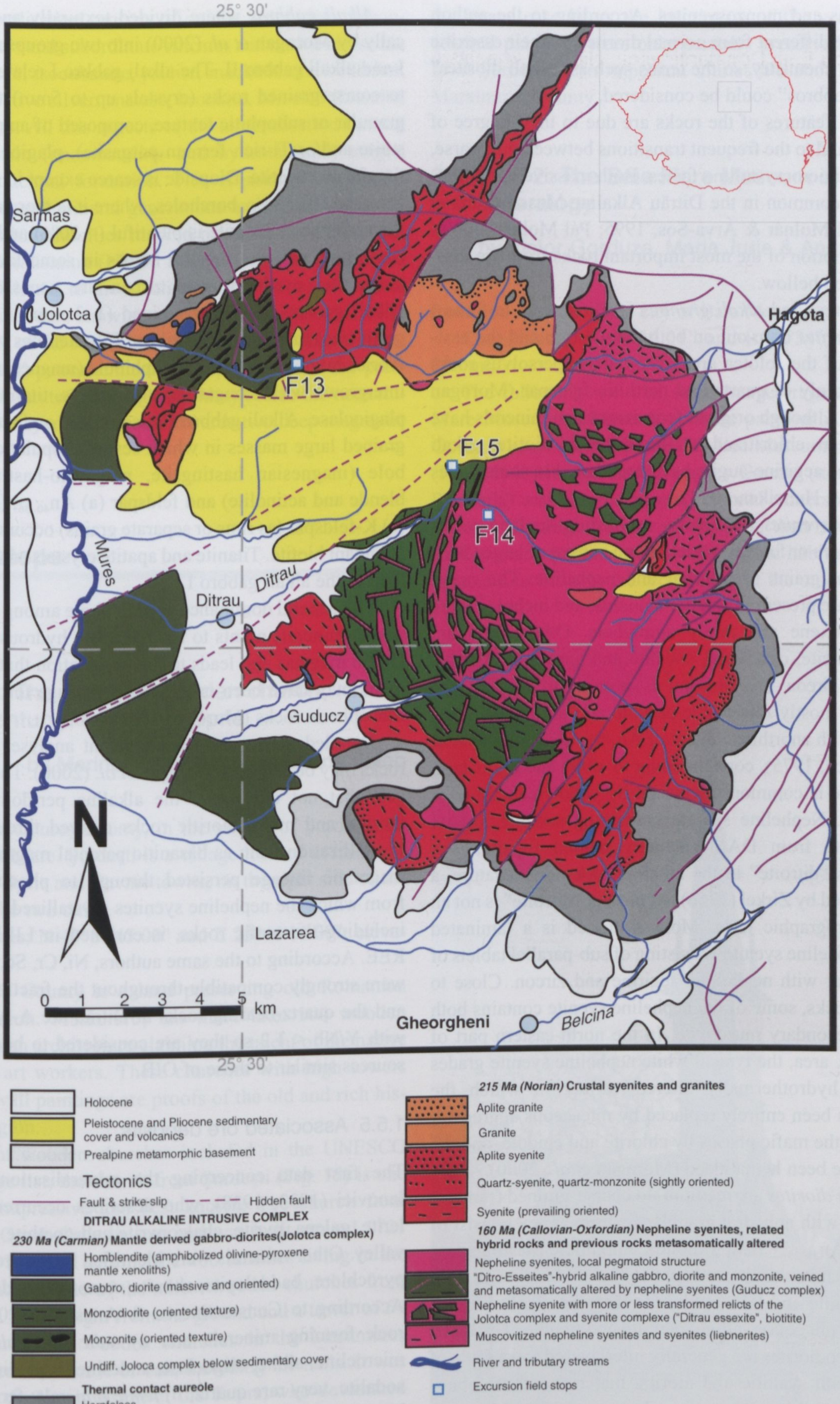

Fig. 14. Geological map of the Ditrău Alkaline Intrusive Complex (modified from Kräutner & Bindea, 1998).

monzodiorites and monzosyenites. According to the author, these rock are different from normal diorites by their essexitic and theralitic chemistry, so the terms such as "alkali diorites" and "alkali gabbros" could be considered.

Structural features of the rocks are due to their degree of crystallinity and to the frequent transitions between the coarse, medium and microcrystalline facies. Both massive and foliated rocks are common in the Ditrău Alkaline Massif (Pană *et al.*, 2000; Pál Molnár & Árva-Sós, 1995; Pál Molnár, 2000). A short description of the most important rocks from the massif is presented bellow.

Granular textured *alkali granites* (grain size up to 5 mm) and *microgranites* crop out on both the western and the eastern margins of the Jolotca area. They are hypersolvus rocks consisting mainly of quartz and perthitic feldspar (Morogan *et al.*, 2000). Although original ferromagnesian minerals have generally been chloritized or limonitized, biotite, alkali amphibole and aegirine-augite have been noted in some facies (Streckeisen & Hunziker, 1974).

Nepheline syenites are coarse- to medium-grained rocks, occur in massive or foliated varieties and consist of large (5–10 mm) euhedral grains of feldspar and nepheline. The mafic components are present in smaller amounts, and include biotite and clinopyroxene and rarely amphibole. Other important phases are calcite, cancrinite, sodalite and analcime. Apatite, titanite and zircon are present as accessory phases. The feldspars are mostly microcline-perthite and antiperthite, and plagioclase with anorthite content of An_4 to An_{28} (Anastasiu & Constantinescu, 1975), corresponding to albite and oligoclase. The nepheline is commonly replaced by yellow cancrinite or blue sodalite. Nepheline syenite containing sodalite, calcite and cancrinite from DAM, actually named foyaite, was referred to as "ditroite" in the alkaline rock nomenclature, a term introduced by Zirkel (1866). At present "ditroite" is not an accepted petrographic term. More restricted is a laminated variety of nepheline syenite consisting of sub-parallel tablets of albitic feldspar with nepheline, aegirine and zircon. Close to the country rocks, some of the nepheline syenite contains both biotite and secondary muscovite. In the north-eastern part of the Ditrău *s.s.* area, the typical white nepheline syenite grades into a red, hydrothermally altered variety in which the nepheline has been entirely replaced by micaceous aggregates (liebenerite), the mafic phases by chlorite and epidote, and the feldspars have been hematitised (Morogan *et al.*, 2000).

The *alkali diorites* are medium- to coarse-grained (rarely > 5 mm) rocks with anhedral granular textures. They consist of plagioclase ($An_{28-25} \pm An_{33} \pm$ albite), amphibole (hastingsite ± kaersutite), titanite, biotite and apatite.The *monzodiorites* contain more biotite and less amphibole than the alkali diorites, together with oligoclase, albite, perthite and titanite. The alkali diorites/monzodiorites are generally interlayered (on a scale of cm to dm) with syenitic and dioritic material and are abundantly transected by veins of nepheline syenite (Morogan *et al.*, 2000).

Alkali gabbros where divided texturally and mineralogically by Morogan *et al.* (2000) into two groups: alkali gabbro I and alkali gabbro II. The alkali gabbro I relates to medium- to coarse-grained rocks (crystals up to 5mm) typically with granular or subophitic texture, composed of amphibole (kaersutite and/or Ti-rich ferroan pargasite), plagioclase (An_{60-23}), titanite and apatite. Diopside is scarce except in some samples from the Ditrău *s.s.* boreholes, where it is more abundant than the amphibole. Titanite is plentiful (> 20%) and large, occurring as crystals up to 1 cm across in some facies. Ilmenite, magnetite, pyrrhotite and zircon are accessory minerals. Alkali gabbro II is finer-grained (1–3 mm or even < 1mm grain-size) than the alkali gabbro I, sometimes with quenched fabrics involving dendritic amphibole (magnesian hastingsite) intergrown with elongate apatite prisms, titanite, biotite and plagioclase. Alkali gabbro II also occurs as fine- to medium-grained large masses in which several populations of amphibole (magnesian hastingsite, magnesio-hastingsitic hornblende and actinolite) and feldspar (a) An_{40-36}, (b) An_{28-13} and (c) K-feldspar (as rims or separate grains) occurs together with abundant biotite. Titanite and apatite crystals are less abundant than in the alkali gabbro I.

The general dominance of amphibole among the ferromagnesian minerals points to the relatively hydrous nature of the Ditrău magmas and leads to the speculation that the primitive melts may have been modified by passage through hydrated lithospheric rocks (Morogan *et al.*, 2000).

Detailed major and trace element analyses of the DAM rocks may be found in Morogan *et al.* (2000). The authors suggest that not only were the alkaline peridotitic, gabbroic, dioritic and monzodioritic rocks derived through fractional crystallization from as basanitic parental magma but that the magmatic lineage persisted through to phonolitic residues from which the nepheline syenites crystallized. The complex, including the mafic rocks, is enriched in LILE, HFSE and REE. According to the same authors, Ni, Cr, Sc, V, Zn and Cu were strongly compatible throughout the fractionation theory and the quartz-bearing rocks at Ditrău are A-type granitoids with Y/Nb < 1.2 so they are considered to be derived from sources similar to those of OIB.

1.5.5 Associated ore deposits

The first data concerning the mineralisations belongs to Ianovici (1933, 1938), who describes occurrences of sphalerite, galena, pyrite, chalcopyrite and goethite in the Jolotca valley. Other minerals were identified in the area: Y-allanite, pyrochlore, baddeleyite, rhönite, xenotime and molybdenite. According to Constantinescu & Anastasiu (2004) the main rock forming minerals are: a) *salic minerals*: orthoclase, microcline, albite, oligoclase, andesine, nepheline, cancrinite, sodalite, very rare quartz; b) *femic minerals*: ferrohornblende, biotite, Ti-augite, diopsidic augite, seldom olivine; c) *accessory minerals*: apatite, titanite, ilmenite, allanite-(Y), epidote, etc. The mineralisation consists of oxides, sulphides, carbonates, phosphates and subordinate silicates and native elements, *i.e.* bismuthinite, isocubanite, joséite, mackinawite, valleriite, tetradymite, native silver, anatase, brookite, Mn-rich ilmenite, pseudobrookite. All this aspects of the mineralisation formed during the main (pneumatolitic and hydrothermal) stages, indicate a sequential formation. This is pointed out by the presence of several mineral generations and by the existence of important discontinuities marked by brecciation intervals. The REE mineralisation (Nb-Th minerals) can be considered genetically affiliated to the alkaline rocks, the mineralogical and geochemical data showing a common geochemical trend for OIB setting of the REE, Ca and Nb with Th. Mineralogical heterogenity and petrochemical incompatibilities – the presence of supersaturated rocks (granitoides) beside the nonsaturated ones (foid syenites) – point towards two deep magmatic sources.

2. Field stops

Day 1

2.1 Stop 1: The Şurdeşti wooden church (18th century), near Baia Sprie

by Marinel Kovacs & Alexandrina Fülöp

Location: Maramureş County, in the village of Şurdeşti, 20 km from Baia Mare. Şurdeşti is a village located at half way between Baia Sprie and Cavnic towns, on the right side of the road linking the two cities.

Coordinates: N 47°37'45.00" and E 23°46'16.00"; elevation: 563 m.

Maramureş County is a land preserving old Romanian cultural tradition. Maramureş has more than 100 wooden churches with an architecture claiming the talent of the native woodcarving art workers. These churches with high towers and original wall paintings are proofs of the old and rich history of the region.

From eight wooden churches included in the UNESCO World Heritage list, the church from Şurdeşti (Fig. 15) is one of the most impressive and best known. The church from Şurdeşti is a Greek-Catholic one and was built around 1721 (Man, 2005). It is still serving the 400 families living in the village. Considered one of the tallest wooden churches from Europe, it has 72 m height from the ground and a tower of 54 m. Like most of the wooden churches in the Maramureş County, it is entirely made of oak, including the nails. It was built up after the last invasion of the Tatars, who devastated the region. The walls were originally painted with biblical scenes from The Old Testament and The New Testament and the image-case bears the inscription of the year 1783. The original paintings were only partially preserved. The church from Şurdeşti is an important tourist site and the symbol of Maramureş County.

2.2 Stop 2: The Baia Mare Museum of Mineralogy

by Victor Gorduza, Maria Jurje & Andrei Gorduza

Location: Centre of the city of Baia Mare.

Coordinates: N 47°39'21" and E 23°34'54"; elevation: 208 m.

The following text and some images regarding the Baia Mare Museum of Mineralogy were previously published by Gorduza *et al.* (2009). The Baia Mare Museum of Mineralogy (Fig. 16) is situated in Maramureş County (northern part of Romania) and has the largest regional mineral collection in Europe. The high number of samples, their special features such as size, spectacular crystallographic habit and particular associations brought the recognition of the uniqueness of this collection.

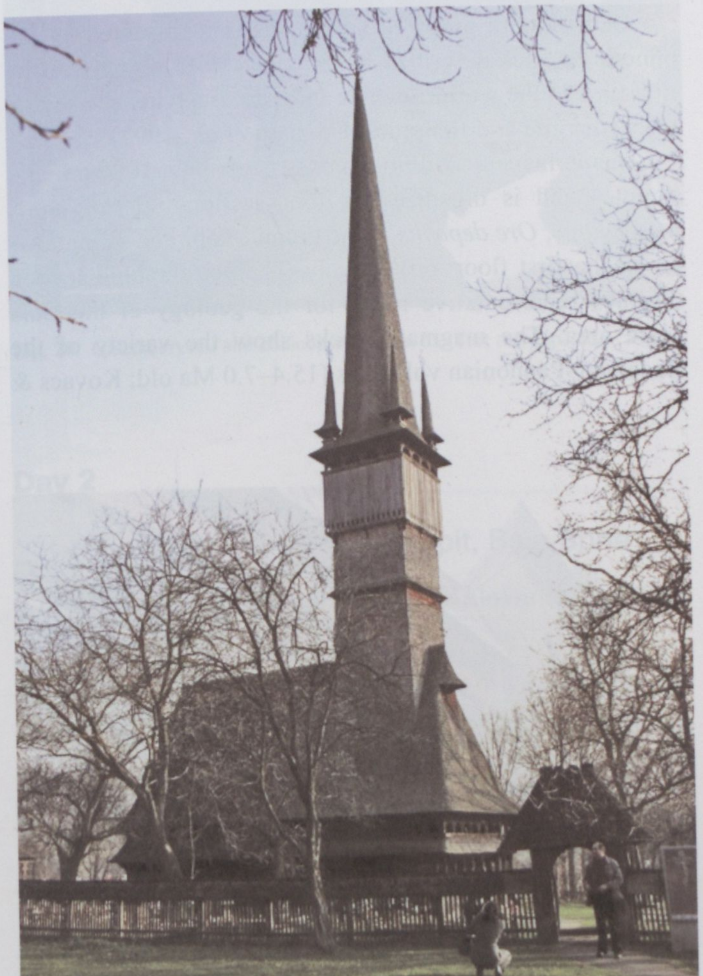

Fig. 15. The wooden church at Şurdeşti, Maramureş County.

The history of the museum collection goes back to the 1960's, with the identification and classification of more than 1300 mineral samples stored in the county museum by the curator V. Gorduza. In 1976, a Natural Sciences *i.e.* Mineralogy section of the museum was established and since than, based mostly on acquisitions, this representative collection for the Baia Mare mining district has been continuously enriched.

For the first time in 1978, the mineral collection was presented as a small temporary exhibition to the public. In November 1989, the permanent mineral exhibition was opened in the actual building. From 1992, it operates as the Baia Mare Museum of Mineralogy – an independent museum, the single cultural institution in Romania focused exclusively on the field of geology–mineralogy.

The museum has more than 16,500 samples from the Neogene hydrothermal ore deposits of the Baia Mare region. Some samples are extremely spectacular, being also included in the Romanian National Heritage (Gorduza, 1978). Over 750 representative ore samples, about 500 petrographic hand specimens covering all rock types occurring in the area, and about 2000 specimens from the Chiuzbaia Scientific Fossil Flora Reservation (situated near Baia Mare), were added to the mineral collection.

An important group of specimens is represented by the mineral species described in the Baia Mare region for the first time in the world, such as andorite, fizélyite, semseyite, klebelsbergite and fülöppite (Udubaşa *et al.*, 1992).

The permanent exhibition consists of about 1000 mineral samples and is organized in four sections: *Petrography*, *Mineralogy*, *Ore deposits* at the ground floor and *Mine flowers* at the first floor, respectively. The petrographic section displays representative rocks for the geology of the Baia Mare area. The magmatic rocks show the variety of the Badenian–Pannonian volcanics (15.4–7.0 Ma old; Kovacs & Fülöp, 2003): basalts, basaltic andesites, andesites, dacites, rhyolites, and the associated hydrothermal products. The sedimentary rocks are represented by clays, sandstones, conglomerates, and evaporites – gypsum samples. The schists, gneisses, pegmatites, and marbles samples are accompanied by explanations about the metamorphic processes. Building stones originating from the area are also displayed: the Buteasa marble, different types of andesites, limestones and sandstones.

Fig. 16. The Baia Mare Museum of Mineralogy.

The mineralogical section shows representative samples for native elements (*e.g.* gold, copper, arsenic), sulphides and sulphosalts (*e.g.* galena, sphalerite, chalcopyrite, pyrrhotite, wurtzite, cinnabarrite, realgar, orpiment, stibnite, pyrite, marcasite, arsenopyrite, chalcostibite, tetrahedrite, freibergite, jamesonite, bournonite, berthierite), carbonates (*e.g.* siderite, rhodochrosite, aragonite, calcite), sulphates (barite, gypsum), (halides), wolframates (wolframite, scheelite), phosphates (vivianite) and silicates (muscovite, pyroxenes, amphiboles). A special attraction is the showcase with fluorescent minerals, such as fluorite and calcite.

The ore deposits section exhibits samples characteristic for the Turţ, Ilba, Nistru, Săsar, Dealul Crucii, Valea Roşie, Herja, Baia Sprie, Şuior, Cavnic, Băiuţ, Răzoare and Baia Borşa ore deposits, the main ore deposits mined in the region. A 3D diagram shows the surface and underground geological structure of the area.

One of the main attractions for the visitors are the so–called "mine flowers", a local term defining the samples with outstanding features found in the area. A "mine flower is a mineral sample collected from the mine, consisting either of a single mineral or an assemblage of different minerals, possessing special aesthetic qualities due to the way the crystals have grown together, due to the colour, shape (habit), or the exceptional sizes of the crystals, qualities which give a well-defined, individual character to each sample when compared with the others" (Victor Gorduza, 1973, *unpubl.*).

The mineral samples and in particular the "mine flowers" display specific and outstanding features: very large, massive aggregates, monomineral pieces and single crystals developed in perfect crystalographic shapes, owergrowth of more generations of the same mineral in a sample, or differently coloured specimens of the same mineral. It is worth to mention the black calcite and half-black half-white calcite spheres (Fig. 17) from the Herja ore deposit, calcite known as "*Kanonenspat*" from the Dealul Crucii ore deposit (described by Udubaşa & Gorduza, 1980), pseudomorphs of saccharoid calcite from Cavnic, or red barite from the Baia Sprie ore deposit (Fig. 18).

Other examples are pyrrhotite from the Herja ore deposit, extremely large and perfectly clear gypsum crystals, as well as the rosettes of rhodochrosite from Cavnic, perfect crystals of vivianite from the Ilba ore deposit, combination of acicular stibnite with barite from Baia Sprie, radial aggregates of

Fig. 17. Half-black half-white calcite sphere (diameter 9 cm) from the Herja ore deposit (from Gorduza *et al.*, 2009).

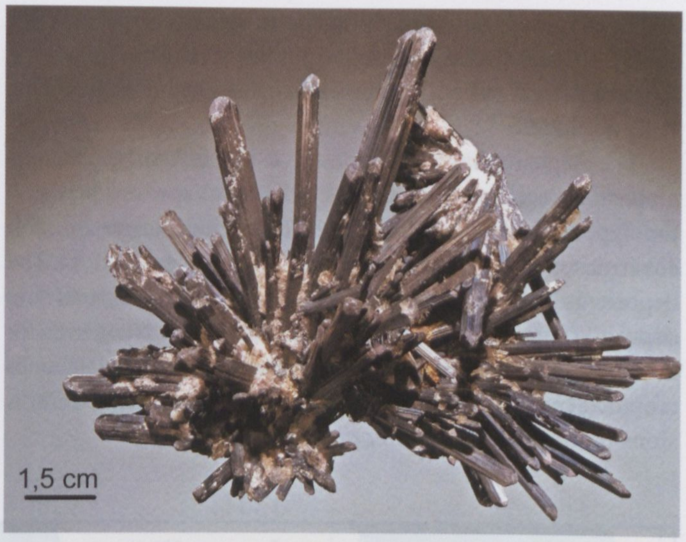

Fig. 19. Aggregates of thick stibnite crystals from the Băiuț ore deposit.

Fig. 18. Red barite crystals from the Baia Sprie ore deposit (from Gorduza *et al.*, 2009).

Fig. 20. Galena crystal and chalcopyrite from the Turț ore deposit.

stibnite from the Băiuț ore deposit and impressive, large galena crystals from the Turț ore deposit (Figs. 19 and 20).

It is worth to mention some mineral rarities: acicular crystals of stibnite over 20 cm in length (Baia Sprie), 2 cm thick stibnite crystals (Băiuț) and gypsum crystals ranging from 60 to 80 cm in length (Cavnic).

Since 1982, the Baia Mare Museum of Mineralogy organized more than 20 temporary exhibitions in Romania and more than 30 exhibitions abroad: *e.g.* Vienna, Graz, Salzburg, Linz, Innsbruck, Paris, Orléans, Lyon, Dijon, Freiberg, Budapest, Monaco, Bruxelles and Hague.
The Baia Mare Museum of Mineralogy became effectively a practical school of mineralogy because of the topics it covers with the exhibition of the mineral and rock samples, as well as the mineral specimens designated for research. The "mine flowers" collection represents a source of inspiration for students in the field of fine arts.

Day 2

2.3 Stop 3: Dealul Minei open pit, Baia Sprie

by Marinel Kovacs & Alexandrina Fülöp

Location: It is located at around 10 km eastwards from the city of Baia Mare, in the vicinity of the town of Baia Sprie (Fig. 3)

Coordinates: N 47°40'12", E 23°42'36"; elevation: 673 m

The Baia Sprie epithermal ore deposit belongs to the Herja–Băiuț metallogenetic field of the Baia Mare Neogene metallogenetic district. A broader summary on the geology of the Baia Sprie ore deposit has been provided by Kovacs & Iștvan (1994), Damian *et al.* (1995) and Kovacs *et al.* (2001) in previous field guidebooks.

The Baia Sprie epithermal ore deposit represents one of the best-known ore deposits in Romania and Europe. The deposit had been mined continuously since the beginning of the XIV[th] century (when it was mentioned for the first time in written documents and called Mons Medius, for Dealul Minei/Mine Hill) until 2006.

The deposits have an impressive richness of the mineralogical association with almost 90 mineral species. It is also the type locality for 6 minerals (andorite, semseyite, felsőbányaite, dietrichite, klebelsbergite and szmikite). The deposit is classified as a "world class hydrothermal ore deposit". The geological background consists of Neogene sedimentary deposits, Sarmatian and Pannonian (the last ones cropping out) and Pannonian volcanics with associated intrusions (according to Gabor *et al.*, 1999, Fig. 21a).

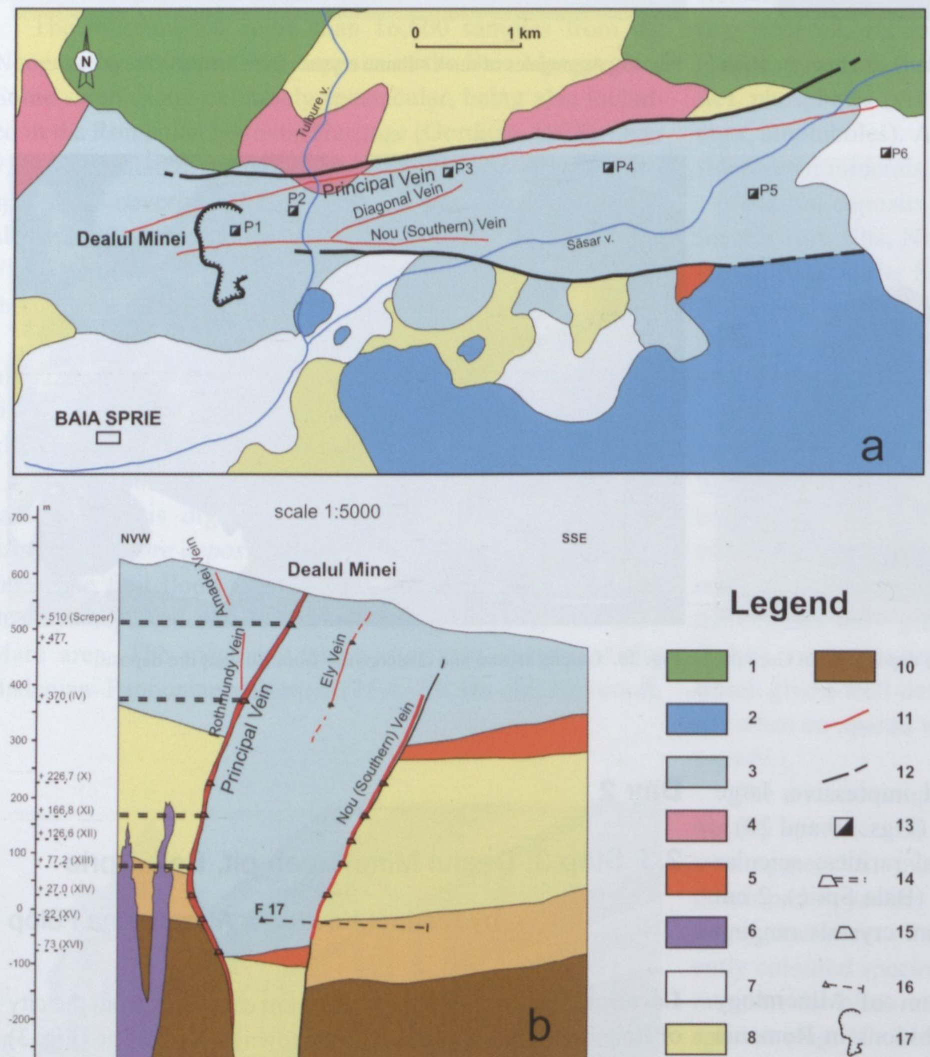

Fig. 21. a) Simplified geological map of the area hosting Baia Sprie ore deposit (after Gabor *et al.*, 1999); b) Geological cross-section through the western part of the ore deposit (modified after Edelstein *et al.*, 1992b).

1 – Pyroxene andesites; 2 –Basaltic andesites with pyroxene; 3 – Pyroxene ± hornblende, quartz andesites (Baia Sprie type); 4 – Quartz andesites; 5 – Biotite dacites (Dăneşti type); 6 – Pyroxene + hornblende andesites (intrusion); 7 – Quaternary; 8 – Pannonian sedimentary deposits; 9 – Sarmatian sedimentary deposits; 10 – Paleogene sedimentary deposits (Flysch type); 11 – Vein; 12 – Fault; 13 – Shaft; 14 – Crosscut; 15 – Adit; 16 – Borehole; 17 – Open pit.

The ore deposit developed in a tectonic structure, *i.e.* a system of two E–W trending faults, marking a graben filled in with a thick pile of volcanic products (more than 700 m in the western part, in Dealul Minei, according to Edelstein *et al.*, 1992b and more than 900 m in the eastern part, according to Iştvan *et al.*, 1996; Figs. 21a,b). This tectonic structure belongs to the Tăuţi–Baia Sprie–Şuior volcano–tectonic alignment, developed along the major wrench/transcrustal fault, Bogdan Vodă–Dragoş Vodă (Kovacs & Iştvan, 1994).

The ore deposit consists predominantly of a vein system including two main veins developed along the faults which delineate the graben: the Principal Vein in the northern part and the Nou (Southern) Vein, in the southern part. Within the graben, NE–SW oriented developed some smaller veins (*e.g.* the Diagonal Vein, Fig. 21a).

With more than 5 km, the Principal Vein is one of the longest hydrothermal veins in Europe. The thickness varies between 0.5 and 22 m and the vein extends vertically on more than 800 m. In the upper part, the Principal Vein has many branches, mostly concentrated in the western part of the ore deposit, in Dealul Minei (the old Mons Medius) area. The Nou (Southern) Vein is 2100 m in length and 0.5–7 m thick and the Diagonal Vein is approximately 600 m in length and maximum 1 m thick.

Some stockworks developed in the western part of the ore deposit, in Dealul Minei.

Since the discovery and the beginning of the mining of the Principal Vein, the knowledge on the geology of the Baia Sprie ore deposit evolved simultaneously with the progress of exploration. During the last decades, certain advances have been made as suggested by the exploration stages visualized in Fig. 22. The complex geological and geophysical studies and the exploration works carried out between the years 1970–1980 showed the eastwards continuity of the Principal Vein, driving to the mining of the Baia Sprie East ore deposit. The Baia Sprie East ore deposit had the largest base metal ore reserves, mined for more than 25 years.

The mineralisation of the Baia Sprie ore deposit has a polymetallic character (lead + zinc + copper + gold–silver). A well-defined vertical zoning was emphasized, especially within the Principal

Vein: gold–silver mineralisation in the upper part, polymetallic mineralisation in the middle part and copper-rich mineralisation in depth. A similar zoning is displayed by the distribution of the hydrothermal alterations (Stanciu, 1973): the chloritic alteration is developed in the deepest zone, in connection with the copper-rich mineralisation, whereas the adularia-sericite and the argillic alterations occur in the middle part of the deposit in connection with the polymetallic mineralisation. The adularia-quartz/sericite + argillic alteration developes mostly in the upper part and it is very well exposed at the surface (Dealu Minei area).

Different types of breccias were described in the eastern part of the ore deposit (Genna *et al.*, 1994; Grancea *et al.*, 2002; Mariaş, 2005): mineralised breccia dykes of hydrothermal explosive origin, breccia veinlets and well-developed breccia pipes suggesting the genetic link between the hydrothermal events and the phreatomagmatic explosions.

The complex mineralogical composition of the Baia Sprie ore deposit was described by many authors all along 150 years of geological research. Some of the most significant mineralogical studies belong to Superceanu (1957), Manilici *et al.* (1965), Petrulian *et al.* (1971) and Borcoş *et al.* (1973, 1975). The minerals occurring in this deposit are:

- native elements: sulphur, arsenic, gold, silver.
- sulphides and sulphosalts: acanthite, andorite, argentite, arsenopyrite, berthierite, bornite, bournonite, chalcocite, chalcopyrite, cinnabar, covellite, diaphorite, fizélyite, freibergite, freieslebenite, galena, jamesonite, kermesite, marcasite, "melnikovite", meneghinite, metacinnabar, miargyrite, millerite, orpiment, pearceite, polybasite, proustite, pyrargyrite, pyrite, pyrostilpnite, pyrrhotite, realgar, semseyite, sphalerite, stephanite, stibnite (Fig. 24a), tetrahedrite, xanthoconite, wurtzite, zinkenite.
- oxides: cervantite, hematite, magnetite, pyrolusite, valentinite.
- carbonates: ankerite, azurite, calcite (Fig. 24c), cerussite, dolomite, malachite, rhodochrosite, siderite (Fig. 24b) .
- sulphates: anglesite, barite (Fig. 24b), chalcanthite, dietrichite, felsőbányaite, gypsum, klebelsbergite, melanterite, szmikite.
- wolframates: scheelite, wolframite (Fig. 24c).
- phosphates and arsenates: diadochite, symplesite.
- silicates: adularia, albite, chlorite, epidote, fibrous microcrystalline quartz (chalcedony), kaolinite, laumontite, quartz, illite.
- halides: fluorite.

New contributions to the Baia Sprie ore mineralogy have been added during the last years. In the upper part of the Baia Sprie ore deposit, Damian *et al.* (2003) described new Ag sulphosalts, such as freibergite (included into galena or associated with pyrite and other silver sulphosalts), stephanite and pearceite–polybasite (associated with freibergite, pyrargyrite and miargyrite). Bailly *et al.* (2002) emphasized a zoning related to the distribution of the

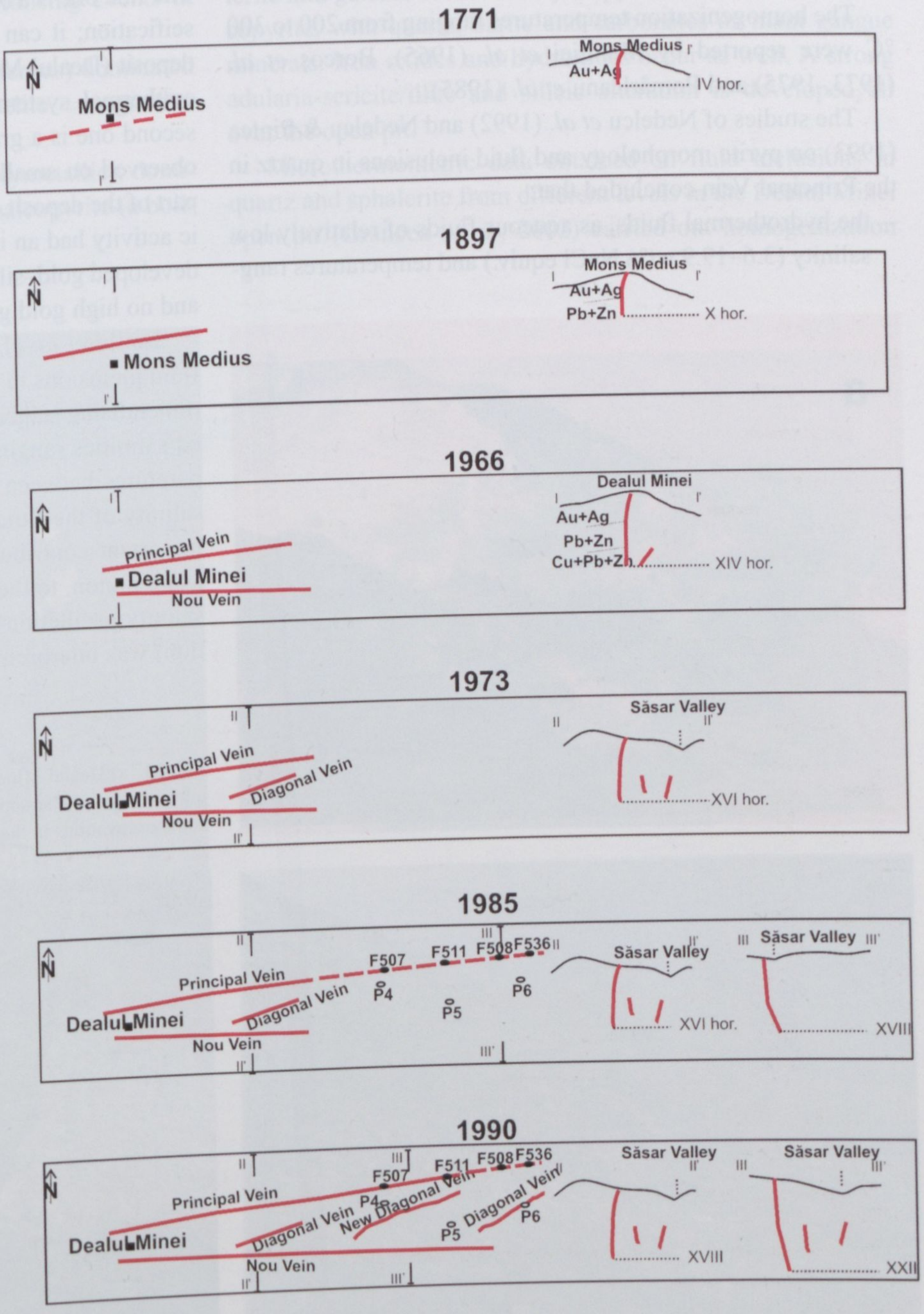

Fig. 22. The evolution of the knowledge of the geology and the exploration stages of the Baia Sprie ore deposit (according to Edelstein *et al.*, 1992b).; hor. = level.

Mn and Fe inside the wolframite crystals from the Principal Vein (17–23.5 wt% MnO in the core and 20–24 wt% FeO in the rim).

Based on the mineral assemblages and the relationships between the ore and the gangue minerals, previous studies in the Baia Sprie ore deposit (Manilici *et al.*, 1965; Borcoş *et al.*, 1975) envisaged two metallogenetic stages. The first is a cupriferous stage with a characteristic assemblage consisting of pyrite, chalcopyrite, magnetite, hematite, scheelite, wolframite, chlorite, quartz, ankerite and barite. It occurs in the Principal Vein and in some branches from the lower part of the ore deposit. The second association, with lead-zinc and gold-silver minerals, represents the main mineralising stage and mainly consists of pyrite, sphalerite, galena, stibnite, tetrahedrite, quartz, calcite and barite.

The homogenization temperatures ranging from 200 to 300 °C were reported by Manilici *et al.* (1965), Borcoş *et al.* (1973, 1975) and Pomârleanu *et al.* (1985).

The studies of Nedelcu *et al.* (1992) and Nedelcu & Pintea (1993) on pyrite morphology and fluid inclusions in quartz in the Principal Vein concluded that:

– the hydrothermal fluids, as aqueous fluids of relatively low salinity (3.6–19.9 wt% NaCl equiv.) and temperatures ranging from 147 to 359 °C upraised from the lower eastern part of the Principal Vein, towards its upper part in the western area (Dealul Minei);
– the boiling processes leading to the main deposition of the ore minerals were initiated by the decompression due to the opening of the main fracture;
– the deposition of the metals took place from the upper part of the Principal Vein; the mixture with the meteoric waters was prevalent in the Dealul Minei area, with gold precipitation as a consequence.

Discussing the character of the mineralisation from the upper part of the Baia Sprie ore deposit, Iştvan *et al.* (1996) postulated two different types of evolution of the hydrothermal system. The first one is a boiling process accompanied by intense degaseification; it can be followed in the western part of the ore deposit (Dealul Minei area), and shows typical features of the epithermal systems with well-defined vertical zonality. The second one is a gradual cooling and local degassing; it can be observed on small areas (quasi-closed system), in the eastern part of the deposit. The different evolution of the metallogenetic activity had an important role in the gold distribution (well-developed gold–silver level in the western part in Dealul Minei and no high gold grades in the eastern part of the ore deposit).

Bailly *et al.* (1998) documented the characteristics of the fluid inclusions in quartz and sphalerite belonging to the main mineralising stages of the Baia Sprie ore deposit. They reported salinities ranging from 0 to 21 wt% NaCl equiv. and temperatures between 150° and 300 °C. The high values of the salinity of the fluids, especially in the first stage, confirm the important contribution of the magmatic source *i.e.* the Baia Mare pluton, to the hydrothermal fluids. The temperature and salinity oscillations during the main stage (Pb-Zn mineralisation) was interpreted by the authors as due to the phreatomag-

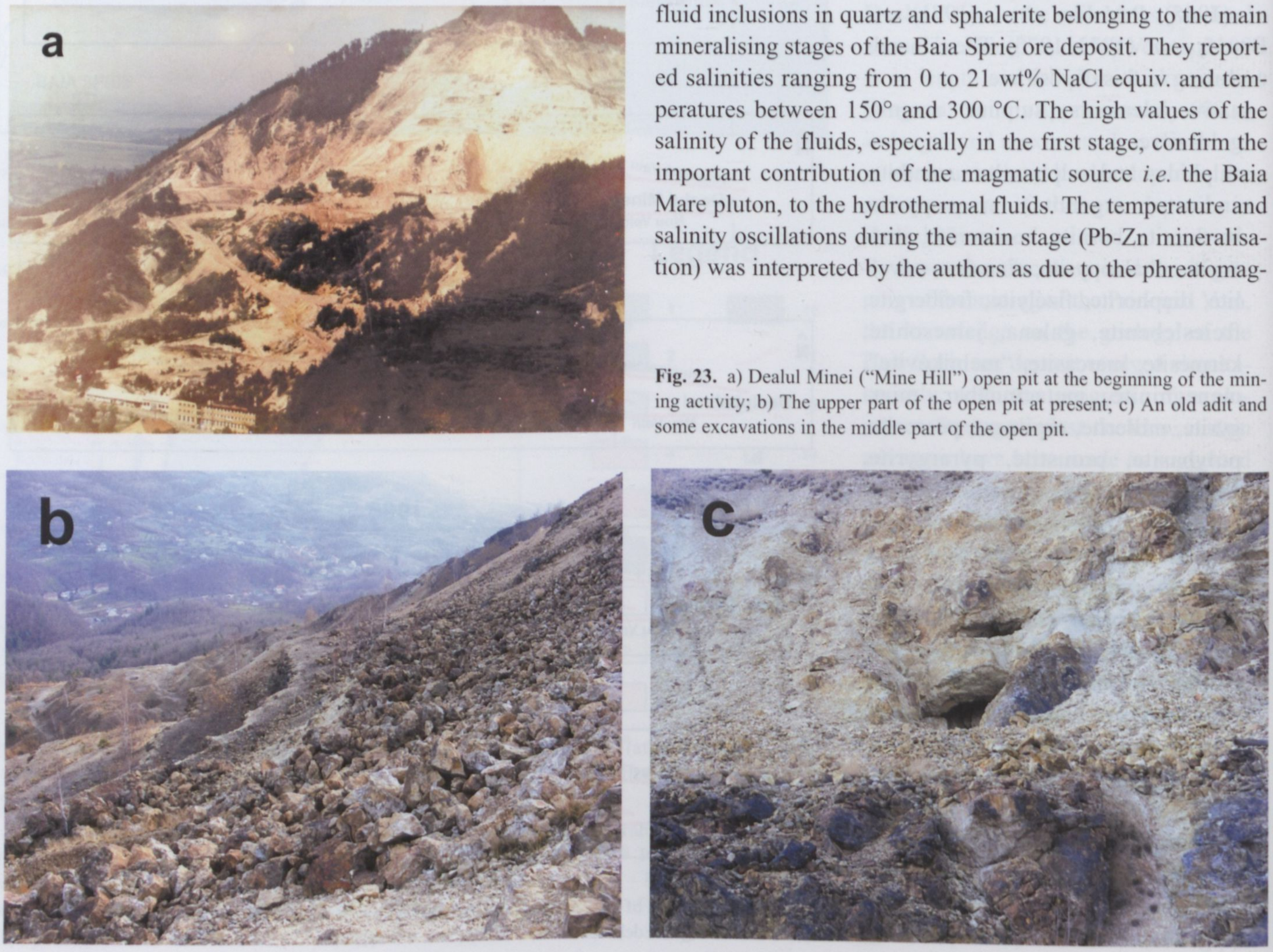

Fig. 23. a) Dealul Minei ("Mine Hill") open pit at the beginning of the mining activity; b) The upper part of the open pit at present; c) An old adit and some excavations in the middle part of the open pit.

matic activity leading to the fluids boiling processes and the emplacement of breccia pipes.

A more recent study (Grancea *et al.*, 2002) describes five mineralising events/stages in the ore-forming system: M1 (Fe), M2 (Cu–W), M3 (Pb-Zn), M4 (Sb) and M5 (Au-Ag). All the five stages are present in the Principal Vein and its numerous branches. Based on the fluid inclusions study and ion content of the quartz crystals analyses, the authors emphasized the Na–K chloride composition of the hydrothermal solutions. The Br/Cl ratio of 0.30 for a sample belonging to M2–M3 stage suggests a magmatic input in the hydrothermal system of the Baia Sprie ore deposit.

In a more recent approach of the Baia Sprie ore deposit, Mariaş (2005) recognized only three mineralising events in the evolution of the ore-forming system:

M1 – the first mineralising event (cupriferous) dominated by the pyrite, chalcopyrite, wolframite, scheelite, ± magnetite, hematite association;

M2 – the second mineralising event (polymetallic), dominated by sphalerite + galena + pyrite and chalcopyrite (a boiling assemblage);

M3 – the third mineralising event, dominated by Ag, Pb-Ag and Cu sulphosalts, associated with quartz and carbonates.

In the Dealul Minei open pit (Fig. 23) the western and upper part of the Principal Vein crops out. Here a base metal with gold-silver mineralisation developed in many branches and small stockworks (Iştvan *et al.*, 1996). High grades of gold and silver mineralisations were mined, even more than one century ago. Native gold, associated with quartz or included in pyrite occurred in some of the branches. The Ag-rich mineralisation from Dealul Minei area consists of Ag sulphosalts included in galena (Grancea *et al.*, 2002, Damian *et al.*, 2003).

The open pit shows mineralised joints consisting of sphalerite and galena, subordinately of pyrite, marcasite and chalcopyrite, with quartz, barite and carbonates as main gangue minerals. Iron oxides and hydroxides occur as well. A strong adularia-sericite/illite and silicic alteration is developed all over the open pit.

Microthermometric data obtained on fluid inclusions in quartz and sphalerite from different levels in the Dealul Minei open pit (Grancea *et al.*, 2002) carried out homogenization

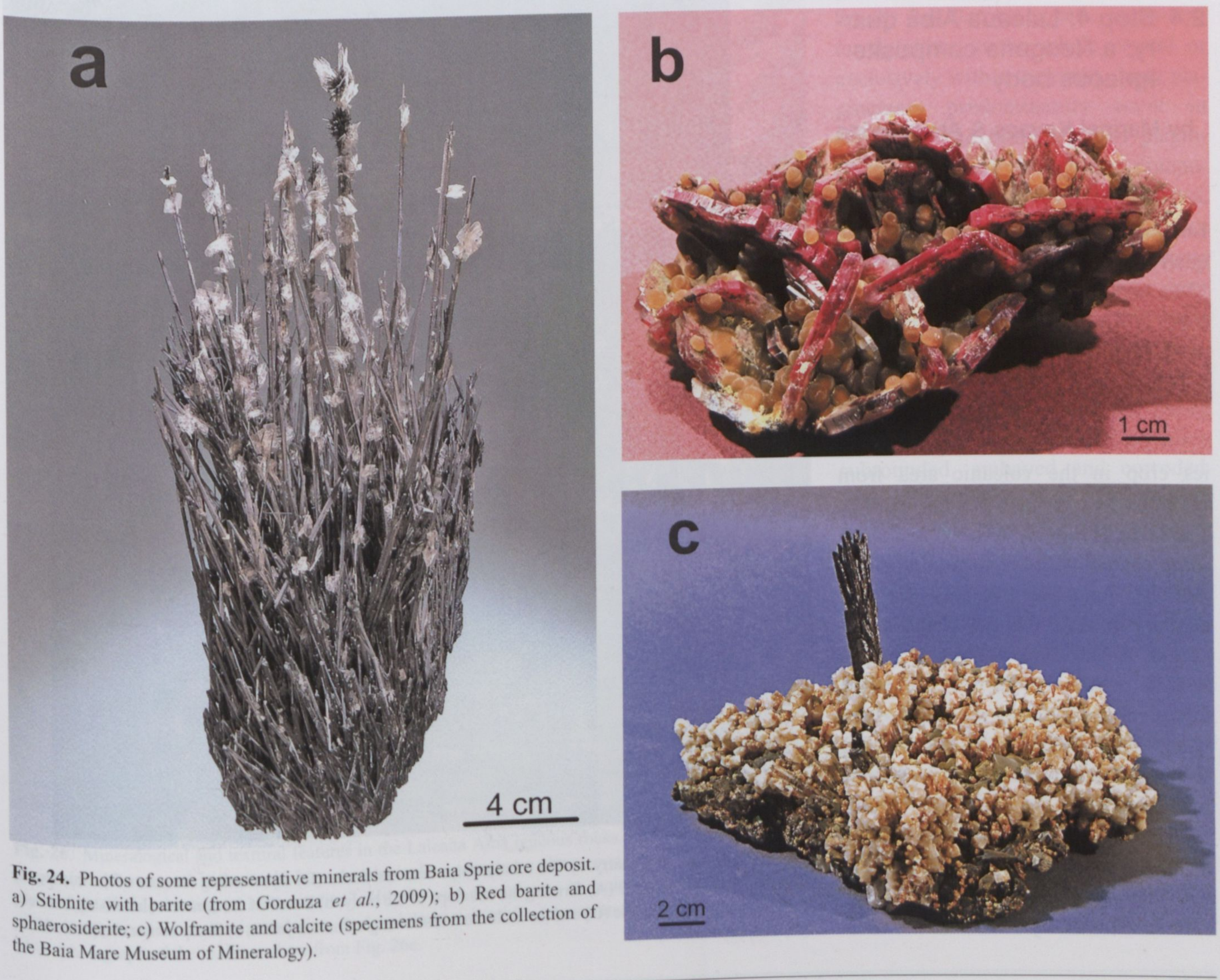

Fig. 24. Photos of some representative minerals from Baia Sprie ore deposit. a) Stibnite with barite (from Gorduza *et al.*, 2009); b) Red barite and sphaerosiderite; c) Wolframite and calcite (specimens from the collection of the Baia Mare Museum of Mineralogy).

temperatures in the range of 176 to 254 °C and salinities in the range of 5 to 15 wt% NaCl equiv. The moderate salinities of the most of the fluid inclusions are considered by the authors to be similar to the Ag-rich epithermal deposits. In the same time, the local variation of the salinities and the presence of vapour-rich inclusions in the quartz growth zones constrained the existence of the boiling processes (Grancea *et al.*, 2002).

The complex evolution of the hydrothermal system from the Dealul Minei area is also suggested by the presence and the relationships between different gangue minerals. In the Baia Mare metallogenic district, the red jasper marks distal and top areas of the epithermal systems (Iştvan *et al.*, 1996). In Dealul Minei upper levels, the red jasper body is crosscut by quartz and polymetallic mineralisation of higher temperature, suggesting a polyascending ore fluids evolution.

The radiometric data (K-Ar and Ar-Ar) performed on adularia and illite from different levels of the Principal Vein and from the Dealul Minei open pit (Lang *et al.*, 1994; Kovacs *et al.*, 1997b) show a range of 9.3–7.7 Ma for the ages of the hydrothermal processes.

2.4 Stop 4: Laleaua Albă quarry: a Neogene composite igneous body

by Marinel Kovacs & Alexandrina Fülöp

Location: The stop is located in the quarry, on the national road linking Baia Mare and Sighetu Marmaţiei cities, at about 20 km from Baia Mare and 10 km north from Baia Sprie (Fig. 3).

Coordinates: N 47°41'19", E 23°46'20"; elevation: 776 m

A series of igneous composite bodies crop in the volcanic area from northern part of the Baia Sprie town. The bodies are well outlined and show sharp contact with the surrounding formations (Pannonian volcanic and sedimentary rocks), thereby being interpreted as intrusive magmatic bodies (Gabor *et al.*, 1999). An alternative interpretation suggests an initial extrusive dome, highly eroded, showing now its erosion remnants as distinct bodies.

The quarry shows a cross section through a composite body consisting of two distinct igneous rocks: a dacitic core surrounded by an andesitic "envelope". The name Laleaua Albă means "the White Tulip" and is due to the shape and the light colour of the dacitic core, contrasting with the dark colour of the surrounding andesite envelope (Fig. 25).

Besides the interesting field relationships of these two types of rocks, the quarry is a real "open air geological museum" showing outstanding mineralogical and petrological features.

The radiometric (K-Ar and Ar-Ar) age of the composite body is 8.5–8.0 Ma (Kovacs, 2002; Pécskay *et al.*, 2006) and corresponds to the youngest volcanic rocks from the Baia Mare region except for the Firiza basalt intrusions, which were dated as 8.1–7.0 Ma (Edelstein *et al.*, 1993).

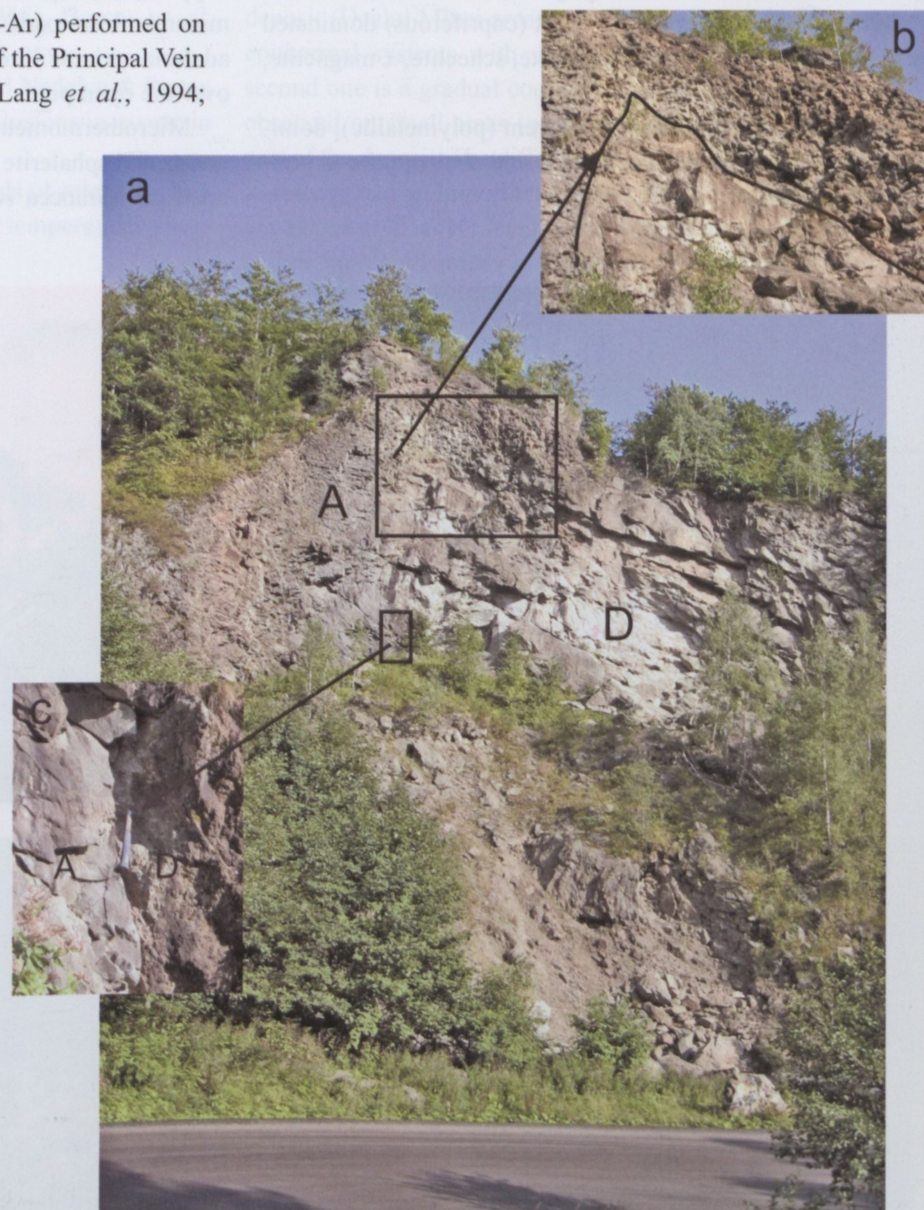

Fig. 25. Laleaua Albă quarry. a) The relationships between dacite (D) representing the core of the composite igneous body and andesite (A) forming the envelope of the body; b) Detail of the contact relationship between the massive textured dacite (D) and the andesite (A) showing columnar joints; c) Sharp contact between dacite (D) and andesite (A).

The dacite core of the composite body has macroporphyritic texture, with large phenocrysts of K-feldspar and plagioclase of maximum 5 cm (Fig. 26). The other phenocrysts are smaller in size, quartz reaching maximum 1 cm and the biotite, amphibole and pyroxene crystals being even smaller.

Abundant mafic microgranular enclaves (MME) of very different sizes, the largest being of 40–50 cm, occur in the dacite core and are less abundant towards the margins of the core. The mafic microgranular enclaves are predominantly of doleritic type, consisting of amphibole + plagioclase + Fe–Ti oxides (Figs. 26e, f). Mafic microgranular enclaves composed of clinopyroxene > amphibole > plagioclase and amphibole + plagioclase ± biotite are subordinate. Radial developed long prismatic crystals of amphibole and plagioclase are the common texture of the enclaves (Fig. 26f).

The outer andesite of the body has dark grey colour, aphanitic to porphyritic texture and shows seldom plagioclase, quartz, biotite, amphibole and pyroxene phenocrysts. The andesite envelope shows columnar jointings with polygonal cross section, contrasting with the inward, massive textured dacite (Fig. 25b). The contact between the inner dacite and the outer andesite is sharp (Fig. 25c) except for some parts of the northern border showing a 3 m wide transitional contact zone. In the outer parts, light colour bands of dacitic composition, mostly consisting of feldspar and quartz, are incorporated in an aphanitic, dark grey andesitic material. Small mafic microgranular enclaves (MME) develop rarely within andesites.

K-feldspar (sanidine) is the most significant mineral in the macroporphyritic dacite. It occurs exclusively in dacite, as large phenocrysts (up to 5 cm) with typical Karlsbad twins, easy to be recognized with naked eyes. The most of the phenocrysts show euhedral habit but resorbed or extensively corroded crystals occur as well. Sanidine contains inclusions of plagioclase, by far the most abundant, biotite, and very rarely amphibole.

The plagioclase crystals belong to at least two generations. Large (>1 cm) phenocrysts occuring exclusively in dacite are euhedral, twinned and commonly shows overgrowths, with low An content (28–43%; Figs. 26a, b, 27a). Often, they consist of zoned cores, more basic in composition, suggesting more likely former xenocrysts. Small, oscillatory zoned, sieve-textured (either in the whole crystal or exclusively within the rims), dusty plagioclases predominantly occur in andesites. The same types of plagioclase crystals are identified as components of the mafic enclaves (Kovacs, 2002). The mafic microgranular enclaves consisting of abundant clinopyroxene with respect to the amphibole phenocrysts contain also the most basic plagioclase (An > 75–80%; Fig. 27a).

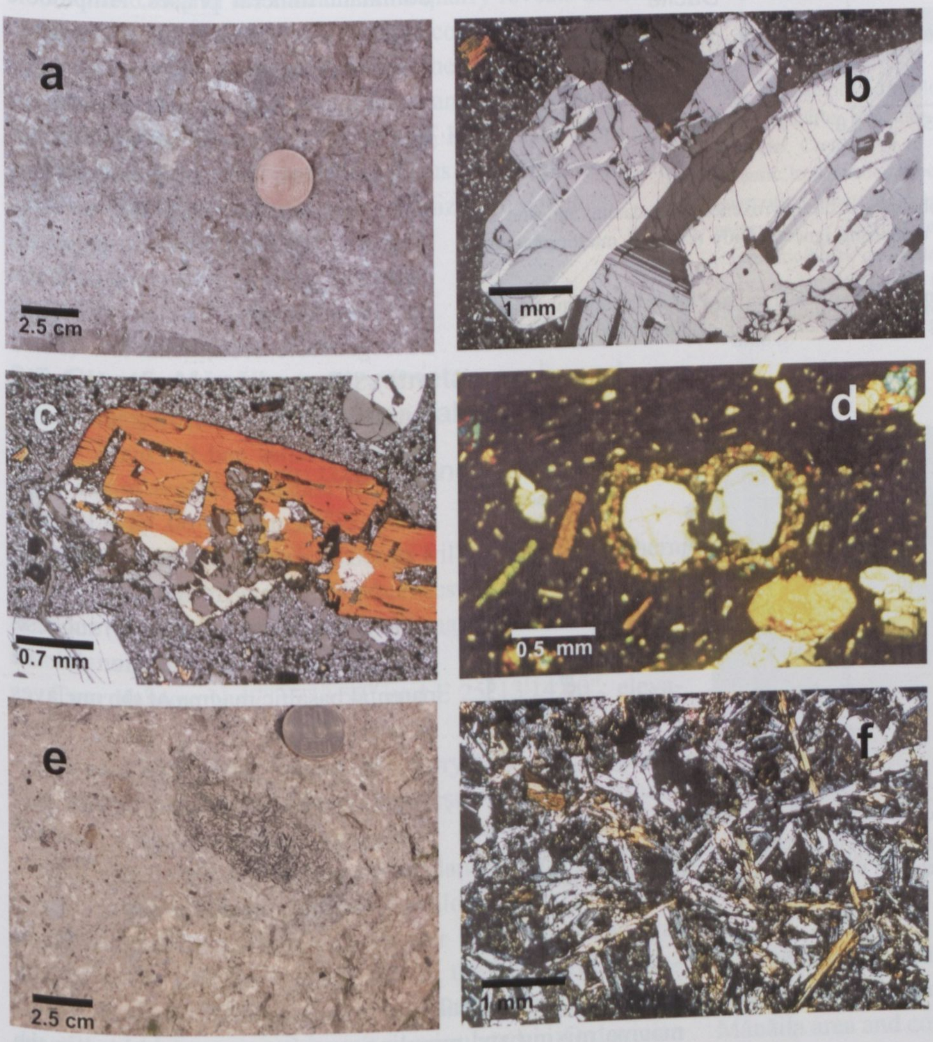

Fig. 26. Mineralogical and textural features in the Laleaua Albă igneous rocks. a) Large K-feldspar and plagioclase phenocrysts in dacite; b) Low-An plagioclase overgrown phenocrysts in dacite; c) Amphibole phenocryst (Ti-Mg-hastingsite) "in reaction" with the acid groundmass in dacite; d) Quartz phenocrysts with clinopyroxene coronas in andesite; e) Amphibole-rich mafic microgranular enclave in dacite; f) Microphotograph of the mafic enclave from Fig. 26e.

The quartz phenocrysts from dacite are larger and more abundant than those found in andesites and are often subrounded, embayed and corroded. The quartz phenocrysts with clinopyroxene coronas are typical for andesites (Fig. 26d).

Pyroxenes are almost exclusively represented by clinopyroxene. They occur in clusters (predominantly in andesites), rarely as single crystals (especially in the mafic enclaves); often zoned and twinned, the clinopyroxene is represented by Cr-diopside. Mg# ranges between 79–95, but the great majority of the values are included in the interval 85–95 (Fig. 27c), according to Kovacs *et al.* (1997a). Clinopyroxenes are very similar in the

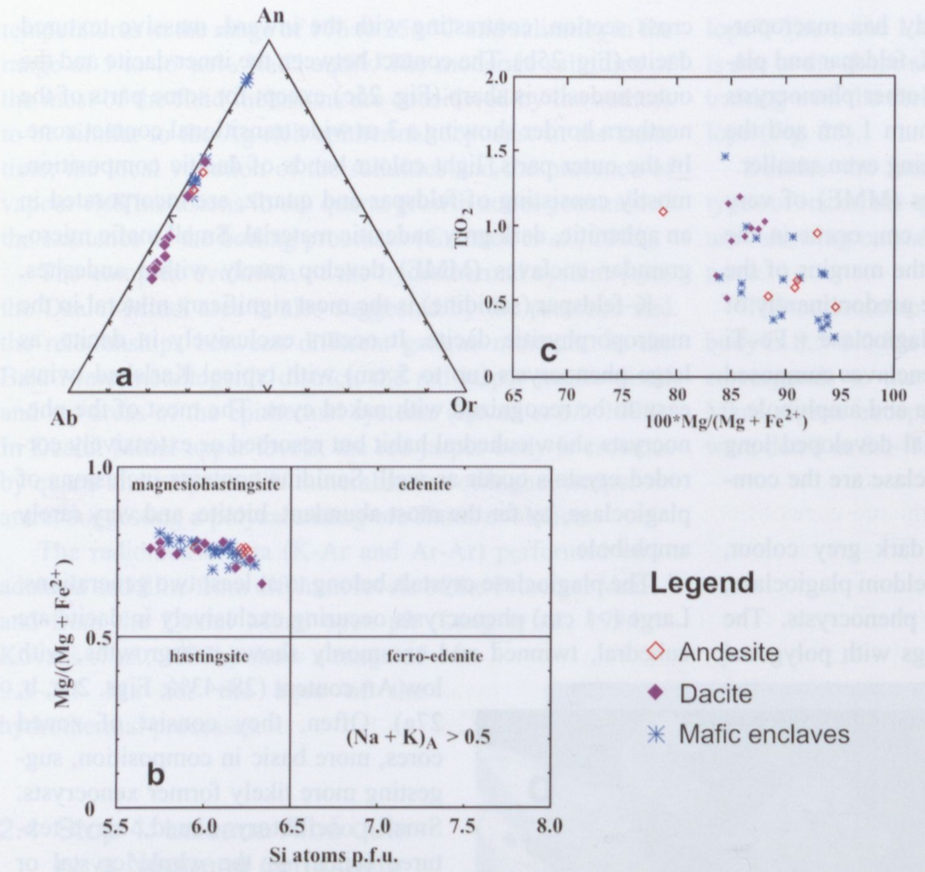

Fig. 27. Mineral chemistry of plagioclases, amphiboles and clinopyroxenes from dacite, andesite and mafic microgranular enclave of the Laleaua Albă composite igneous body (electron microprobe data, according to Kovacs *et al.*, 1997a; Kovacs, 2002).

a) Plot of the plagioclase composition in the Ab–An–Or ternary diagram; b) Plot of the amphibole composition in the Mg/Mg+Fe – Si diagram (according to Leake *et al.*, 1997); c) Plot of the clinopyroxene composition in the Ti – Mg/Mg+Fe diagram.

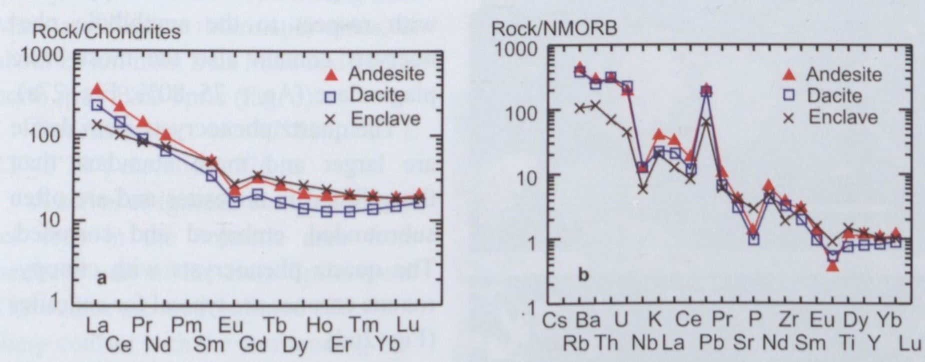

Fig. 28. Trace elements normalized diagrams for the Laleaua Albă dacite, andesite and mafic microgranular enclave (according to Kovacs, 2002). a) REE distribution in the chondrite-normalized diagram; b) N-MORB-normalized diagram showing similarities between the dacite, andesite and mafic microgranular enclave patterns.

three rock types representing xenocrysts in dacites and andesites.

Amphiboles of dacites, andesites and mafic enclaves are exclusively of high Mg# (71–84) Ti–magnesiohastingsite (Fig. 27b). The amphibole phenocrysts from dacites are abundant and have larger sizes than those from andesites and show sometimes "reaction" with the surrounding acid groundmass (Fig. 26c). Amphiboles of andesites are frequently replaced by an assemblage consisting of pyroxene + plagioclase + Fe oxides. Biotite occurs as large phenocrysts in dacites and it is more abundant compared with andesites. It occurs only accidentally in the mafic microgranular enclaves. Overall, biotite is represented by the intermediate terms of the phlogopite– annite series, with low Fe/Mg ratios (Kovacs, 2002).

In the transitional zone from the northern contact between the macrophyritic dacite and the aphanitic andesite, the sieve-textured plagioclase, clustered clinopyroxene and quartz with pyroxene coronas are the dominant mineral phases. Amphibole and biotite are less abundant and smaller in size than in dacites.

The geochemical data pointed out only small differences between dacites and andesites, both of them showing high SiO_2 content (63–66.5 wt% in dacites and 61.0–62.5 wt% in andesites) compared with the most common mafic enclaves (amphibole-rich doleritic/microgabbroic rock) with low (50.02 wt%) SiO_2 content, respectively. In the same time, there is a big difference between dacites and the mafic microgranular enclaves related to the compatible elements (V = 60, Cr = 17, Ni = 4 ppm for dacites and V = 315, Cr = 249, Ni = 46 ppm for the mafic microgranular enclaves, respectivly) suggesting a "primitive" composition for the parental basaltic magma of the enclaves (Kovacs, 2002).

The similar pattern of the trace elements normalized diagrams (Figs. 28a, b) suggests a common magmatic source, a subduction-related calc-alkaline magma for the both dacite and andesite, as well as for the mafic enclaves (Kovacs, 2002).

The mineralogical and geochemical data suggest that magma mixing and mingling processes were involved in the generation of the two rock types forming the Laleaua Albă composite body. Two different magmas, a basic magma (similar to those of the gabbroic type of mafic enclaves) and an acidic one (a silicic composition in equilibrium with K-feldspar, low-An plagioclase, quartz and biotite from the macroporphyritic dacite) had been mingled and mixed before the body emplacement.

The presence in dacites of the high Mg# clinopyroxenes and magnesiohastingsites, typical for the gabbroic enclaves, asserts the involvement of the mixing processes. Other constraints of the magma mixing processes are the presence of the pyroxene and amphibole xenocrysts in both dacite and andesite, the presence of the plagioclase xenocrysts in dacite, as well as of the crystals of quartz with pyroxene coronas in andesite.

The magma mingling processes are also constrained by the presence of the crystal clusters (pyroxene + plagioclase + Fe-Ti oxides) and abundant clinopyroxene clusters in the two types of rocks and especially in andesites, the presence of the abundant mafic microgranular enclaves in dacites, as well as of some feldspar and quartz-rich bands suggesting dacitic magma in the transitional zone, at the contact between dacite and andesite.

The field stop in the Laleaua Albă quarry reveals the striking field relationships between the light colour of the core composed of macroporphyritic dacite and the dark–grey colour of its "envelope", consisting of aphanitic andesite. It shows also the outstanding large sized crystals of K-feldspar (sanidine) and plagioclase, as well as the numerous mafic microgranular enclaves (MME) with a wide range of sizes, in dacite.

Day 3

2.5 Stop 5: Mănăila quarry (metamorphosed base metal deposit) near Valea Putnei

by Ovidiu Gabriel Iancu & Ciprian Popa

Location: 6 km NE of Valea Stânei village on the southern slope of Mănăila Peak from Obcina Mestecănişului (Fig. 29), at 8 km from the junction with the national road 18 from Iacobeni village to Baia Mare city.

Coordinates: N 47°35'33.50" and E 25°13'14.00"; elevation: 1190 m

The rocks cropping out in the quarry (Fig. 30) belong to the Tulgheş metamorphic unit, Leşu Ursului sub-unit (Balintoni *et al.*, 2009).

The Tulgheş terrane represents an island arc complex related to the easternmost part of the Avalonian microcontinent that rifted off Gondwana in the lower Ordovician and was docked to the East European craton in the Late Ordovician–Lower Silurian (Munteanu & Tatu, 2003). As previously described, this metamorphic unit accumulated in Ordovician time was divided by Vodă (1993) into four "formations", named (from bottom to top) *Căboaia sub-unit* (Tg1) – Quartzitic formation, *Holdiţa sub-unit* (Tg2) – Quartzitic-graphitic formation, *Lesu Ursului sub-unit* (Tg3) – Volcano-sedimentary rhyolitic formation and *Arşiţa Rea sub-unit* (Tg4) – Phyllitic-quartzitic formation. The 3rd sub-unit occurs in the Mănăila area and consists of metamorphosed sedimentary volcanogenic sequence, represented by two prevailing rock types (quartzites and quartz-feldspathic rocks). They contain an important accumulation of stratiform metallic sulphides. Three main types of mineralisation are exploited here:

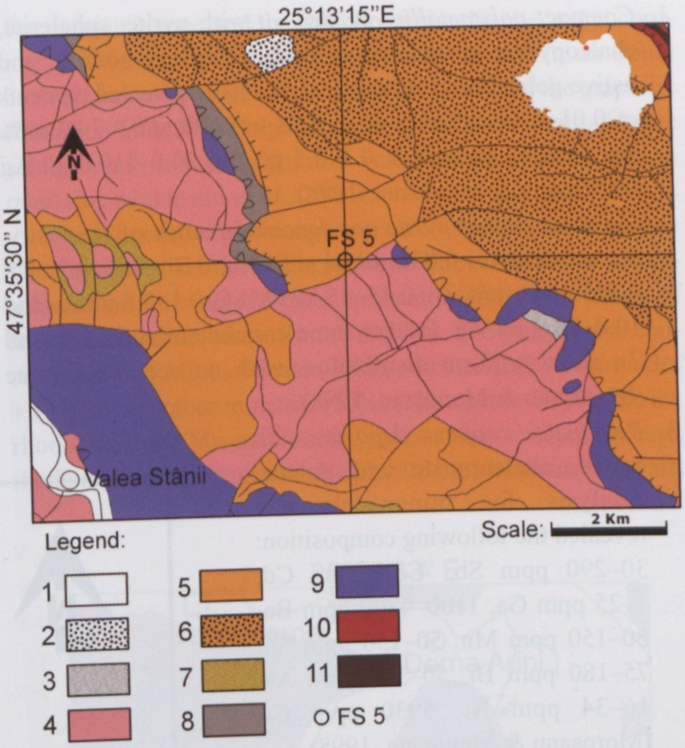

Fig. 29. Simplified geological map of the area hosting Mănăila ore deposit (modified after Kräutner & Bindea, 2002). 1 – Holocene, alluvial deposits; 2 – Upper Cretaceous to Paleocene conglomerates, sandstones, marls; 3 – Jurassic to Triassic carbonates and detritals; 4 – Tulgheş terrane (Phyllitic-quartzitic formation); 5 – Tulgheş terrane (Volcano-sedimentary rhyolitic formation); 6 – Tulgheş terrane (Quartzite formation); 7 – Tulgheş terrane (Graphitic/black quartzite formation); 8 – Negrişoara metamorphic unit; 9 – Rebra metamorphic unit (Voşlobeni sub-unit); 10 – Bretila metamorphic unit (Rarău sub-unit); 11 – Bretila metamorphic unit (Rarău augen gneisses); FS 5 – Stop 5.

Fig. 30. Metamorphosed base metal deposit in Mănăila Quarry.

1. *Compact polymetallic ore deposit* with pyrite, sphalerite, chalcopyrite, galena, tetrahedrite, covellite, bornite, and native gold. The chemical analyses have revealed contents of 0.01–6.31 wt% Cu, 0.01–8.28 wt% Pb, 0.02–7.40 wt% Zn, 0.35–47.40 wt% S, 0.1–3.5 g/t Au, 20.0–110.0 g/t Ag (Moroşanu & Munteanu, 1998).
2. *Compact copper-pyrite ore deposit.* In terms of chemistry, the ore contains 0.038–10.04 wt% Cu, 0.01–3.86 wt% Pb, 0.043–6.43 wt% Zn, 0.45–45.80 wt% S, 0.1–2.8 g/t Au and 10.0–70.0 g/t Ag. Except some enrichment zones, Pb and Zn show uniform distribution, with no economic value (Moroşanu & Munteanu, 1998).
3. *Porphyry copper deposit* with pyrite, chalcopyrite and galena. Analysis for minor elements revealed the following composition: 30–290 ppm Sb, 4–74 ppm Cd, 1–25 ppm Ga, 1100–4800 ppm Ba, 50–150 ppm Mn, 50–150 ppm Sn, 75–180 ppm Bi, 50–320 ppm As, 16–34 ppm Ni, 5–30 ppm Co (Moroşanu & Munteanu, 1998).

2.6 Stop 6: Negoiul Românesc sulphur quarry in Gura Haitii

by Ovidiu Gabriel Iancu

Location: Călimani Mts., 30 km SW of Vatra Dornei, on the road from Vatra Dornei to Topliţa, 9 km away from Gura Haitii village

Coordinates: N 47° 6'41.20" and E 25°14'24.40"; elevation: 1539 m.

A small postcaldera stratocone with its highest point in the Negoiul Românesc peak (1840 m) developed in the interior of the Călimani caldera (Fig. 31) (Seghedi & Szakács, 1997). A very large open-pit sulphur mine opens the interior of the Negoiul Românesc volcanic edifice. In the numerous step walls of the quarry the stratovolcanic structure consisting of alternating pyroxene andesite lavas and pyroclastics pierced by breccia bodies (pipes?) is exposed. The primary volcanological details are largely masked by the pervasive hydrothermal alteration overprint. Slightly altered or even fresh lava rocks were found at the peripheral parts of the volcanic edifice, today largely removed by the mining works. A fresh pyroxene andesite lava belonging to the volcano yield a K-Ar age of 6.75 ± 0.45 Ma (Pécskay *et al.*, 1995).

Postvolcanic processes led, in places, to intense pervasive alteration of the volcanic deposits. The hydrothermal alteration processes were controlled by elements of the volcanic edifice (volcanic feeding conduit), tectonic features (fractures) and lithologic entities (levels of pyroclastic deposits). Strong acid leaching in the vicinity of circulation paths, leaving behind a spongy siliceous rock ("secondary quartzites") predates the precipitation of hydrothermal minerals. Two mineral assem-

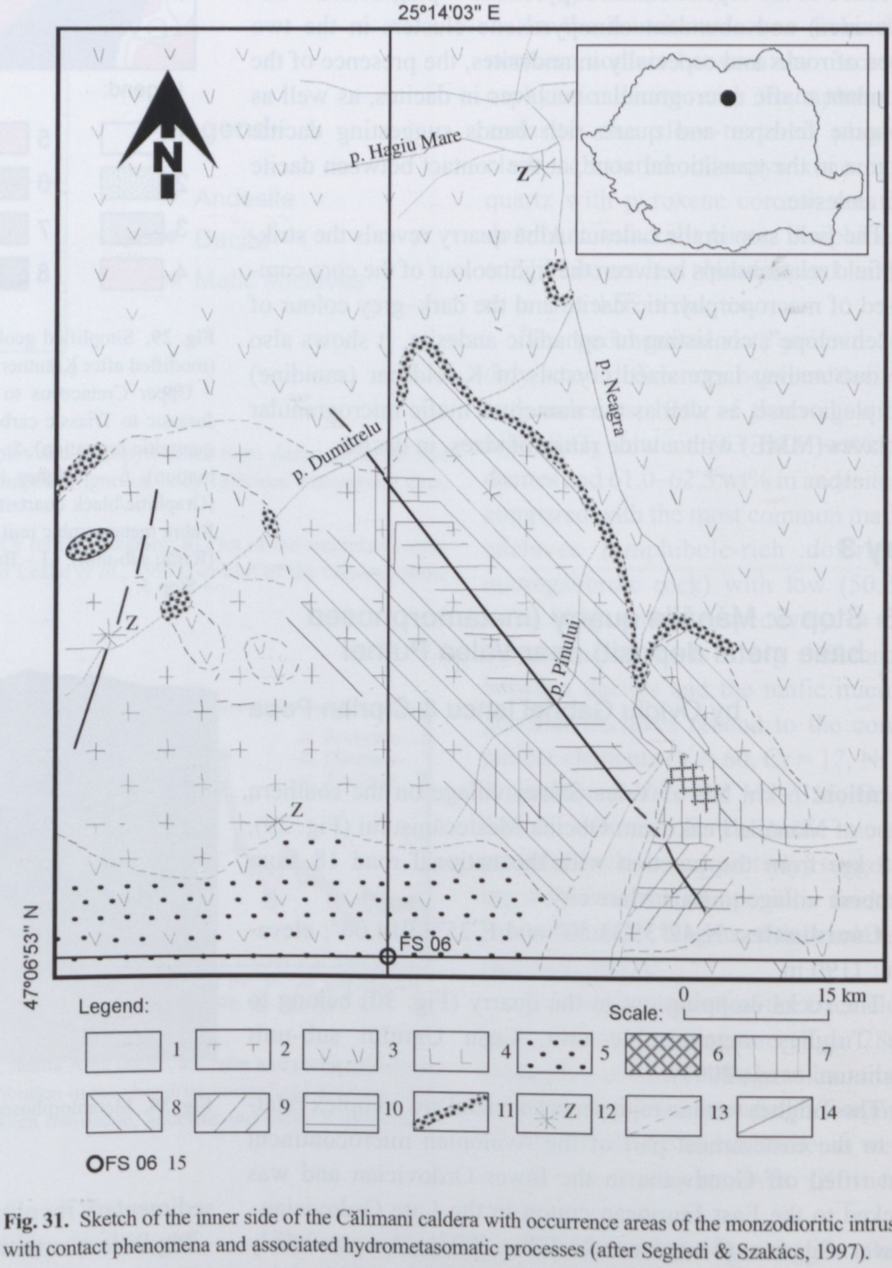

Fig. 31. Sketch of the inner side of the Călimani caldera with occurrence areas of the monzodioritic intrusion with contact phenomena and associated hydrometasomatic processes (after Seghedi & Szakács, 1997).

1 – Quaternary deposits; 2 – Monzodioritic resurgent postcaldera intrusion; 3 – Post-caldera volcanic rocks; 4 – Precaldera volcanic rocks; 5 – Pervasive low-temperature hydrothermal alteration related to the sulphur deposition in the Negoiul Românesc stratocone; 6-11: Thermal and hydrometasomatic contact rocks associated to the monzodioritic intrusion, 6 – Quartz-sericite-tourmaline zone; 7 – Argillic zone; 8 – Actinolite zone; 9 – Biotite zone; 10 – Albite zone; 11 – Thermal contact zone (hornfelses); 12 – Zeolite occurrence; 13 – Geological limit; 14 – Fractures; 15 – Field stop 06.

blages with contrasting redox conditions have been identified: (1) an alunite-bearing association indicating an oxidic environment (quartz, alunite-natroalunite, kaolinite ± zunyite, illite, barite, pyrite, or cristobalite, tridymite, alunite, quartz, kaolinite), and (2) another native sulphur one, of anoxidic environment (quartz, kaolinite, montmorillonite, sulphur ± pyrite, marcasite, melnikovite) (Stanciu & Medesan, 1971a; Seghedi *et al.*, 1992). Red-coloured secondary quartzites impregnated by iron oxides-hydroxides are visible in the upper part of the quarry, whereas its lower parts are white and yellow, due to the ubiquitous presence of clay minerals and sulphur, respectively.

Since the abandoned sulphur quarry is currently under environmental rehabilitation process, a number of features presented above are not visible anymore.

2.7 Stop 7: Ulm quarry (metamorphosed Mn deposit) in Dorna Arini

by Ovidiu Gabriel Iancu & Ciprian Popa

Location: East Carpathians, 6 km SV of Dorna Arini village, on the road to Vatra Dornei city. Coordinates: N 47°17'32.30" and E 25°24'33.40"; elevation: 1200 m

The Ulm quarry (Fig. 32) is located in the Crystalline-Mesozoic Zone of the Eastern Carpathians, more precisely in the Tulgheş unit of the Subbucovinian Nappe (Balintoni *et al.*, 2009). The Tulgheş terrane derived from Ordovician sediments and volcanics (Vaida, 1998), formerly assigned to the Cambrian. The Tulgheş terrane derrived from Ordovician sediments and volcanics (Vaida, 1998) and consists of several sub-units, from which the second one, called Holdiţa, crops out in the Ulm quarry.

Holdiţa sub-unit (Tg2), quartzitic-graphitous (Fig. 33), occurs along the East Carpathians, in the basement of both the Bucovinian Nappe and the Subbucovinian Nappe and according to Kräutner & Bindea, (2002), was formed in an initial basinal phase. The Tg2 formation is also named "the graphitic formation" due to the organic matter from the sericite-chlorite schists and black quartzites (cherts metamorphosed to quartzite; Munteanu *et al.*, 2004).

The syngenetic ferromanganese carbonate-silicate deposit at Ulm, is located in the Holdiţa sub-unit. The ore is hosted by cataclased and microfolded black quartzites, and forms lenses of small and medium sizes, from 5 to 20 m. The primary ore consist mainly of Mn carbonate (70%), silicates (20%) and oxides + sulphides + other minerals (10%) (Hârtopanu, 2004). Fe-rich rhodochrosite, Mn-amphibole, spessartine, stilpnomelane, rhodonite, pyroxmangite and tephroite are the main minerals.

Fig. 32. Metamorphosed Mn deposit in Ulm Quarry.

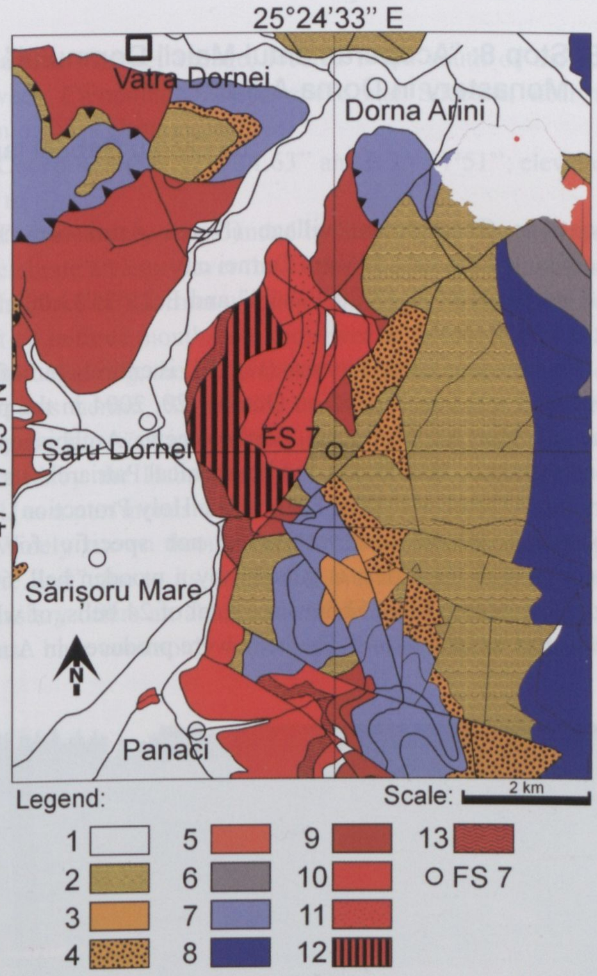

Fig. 33. Simplified geological map of the area hosting Ulm ore deposit (modified after Kräutner & Bindea, 2002)

1. Holocene, alluvial deposits; 2. Tulgheş terrane (Volcano-sedimentary rhyolitic formation); 3. Tulgheş terrane (Quartzite formation); 4. Tulgheş terrane (Graphitic/black quartzite formation); 5. Tulgheş terrane (not differentiated); 6. Negrişoara metamorphic unit; 7. Rebra metamorphic unit (Ineu sub-unit); 8. Rebra metamorphic unit (Izvoru Roşu sub-unit; 9. Bretila metamorphic unit; 10. Ulm gneisses (massive), Bretila metamorphic unit; 11. Ulm gneisses (foliated), Bretila metamorphic unit; 12. Panaci gneiss – amphibolite association, Bretila metamorphic unit; 13. Pârâul Rusu white quartz-feldspar gneisses, metamorphic unit; FS 7 – Stop 7.

The secondary ore resulted from supergene alteration of primary mineralisation is represented by Mn and Fe oxides and oxy-hydroxides (*e.g.* psilomelane, pyrolusite, goethite, *etc.*). With respect to their mineralogical composition and texture, two ore types may be distinguished inside Ulm quarry: banded and massive. The banded ore is composed of mm-thick stripes of different colour, corresponding to the dominant mineral: carbonate (pink or gray), amphibole (green or white), spessartine ± stilpnomelane (brown-yellow), quartz (white or colourless) or oxide (black). Carbonate commonly occurs as fine-crystallized masses, but also may form coarser (up to 3 mm) crystalline aggregates or veins. The massive ore consists of grey or pink compact rocks composed of Mn carbonate (70–90 wt%) with minor quartz, silicates and oxides. Garnet, amphibole, tephroite, rhodonite and pyroxmangite are the most common silicate minerals (Munteanu *et al.*, 2004).

2.8 Stop 8: "Acoperământul Maicii Domnului" Monastery in Dorna Arini

by Ovidiu Gabriel Iancu

Location: Gheorghițeni village (Dorna Arini commune, Bucovina), 4 km east of Vatra Dornei city

Coordinates: N 47°20.4'18.00" and E 25°25'33.00"; elevation: 1000 m.

The new monastery for nuns (Fig. 34) is entirely built from wood and was consecrated on October 20, 2004 in the presence of His All Holiness, Bartholomew, Archbishop of Constantinople, New Rome and Ecumenical Patriarch. Its celebration is October 1st (The Feast of the Holy Protection). The monastery, whose architecture is not specific for the Bucovinian monasteries, is guarded by a wooden bell, 60 m high. The belfry (Fig. 35) houses a total of 24 bells, of which the largest weighs 5 tons. The bells were produced in Austria and are connected to a central computer system harmonized at the service of prayer and watches. Their voice is heard to the city of Vatra Dornei, located five miles away.

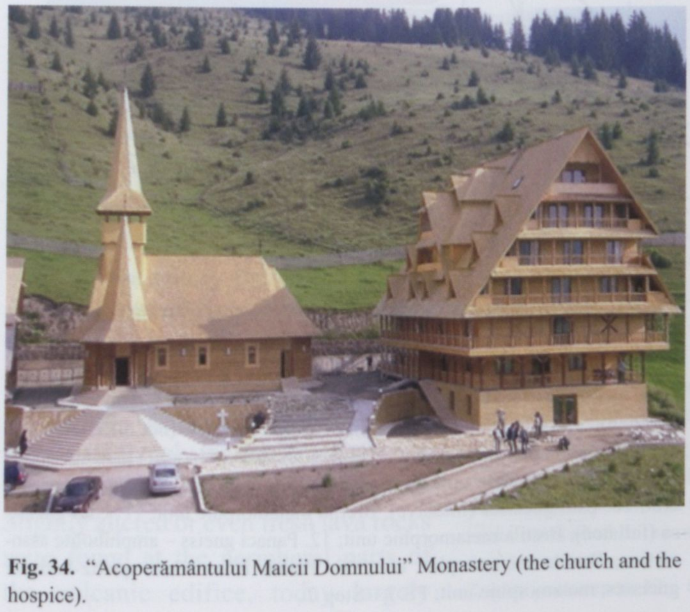

Fig. 34. "Acoperământului Maicii Domnului" Monastery (the church and the hospice).

Day 4

2.9 Stop 9: Moldovița Monastery (16th century) in Vatra Moldoviței

by Ovidiu Gabriel Iancu

Location: Bucovina, Vatra Moldoviței, 27 km north of Câmpulung Moldovenesc, in the village of Vatra Moldoviței, on the flat piece of river bed between the Moldovița and Ciumarna rivulets, in a pictorial landscape of the forested Bucovinean Muntains.

Coordinates: N 47°41'10.46" and E 25°32'40"; elevation: 640 m.

The Moldovița Monastery (Fig. 36) is one of the oldest monachal settlements in the northern Moldavia. The first

Fig. 35. Belfry of the "Acoperământului Maicii Domnului" Monastery.

stone church of the monastery was erected under the peaceful ruling of Alexander the Good (Alexandru cel Bun) and it was documented between 1402 and 1410 as a cultural centre. It functioned until the late 15th century when it collapsed due to a landslide (the ruins can be seen today, not far from the present building). Prince Petru Rareș, an art lover and protector just like his father, Stephen the Great (Ștefan cel Mare), built the present Moldovița church in 1532 (Irimia, 2008).

The second (to be erected) after Humor, the church is the last one to have an open porch as well. The features that characterize the style used in architecture in the era of Stephen the Great (1433–1504), namely the vault, the tomb room, recesses in the apses, niches under the cornice, window and door frames with a broken arch and rosettes shaped as clubs, and elements of Gothic influence, were preserved (Pascu, 2007).

The church of the Moldovița Monastery is a real jewel of the mediaeval Romanian art, among the other Bucovinean churches unique in this world, whose fame has exceeded the country borders since long time ago. It has an important historical and artistic significance due to the original painting and architecture, the vivid colours and the freshness of the painting covering the entire church building defying the unfavourable and severe climate of the Northern Moldavia. The painting of the monastery shows both Byzantine influence and specific Moldavian motifs: landscapes, mountains, flowers, costumes, towels etc. The external walls are painted with religious scenes and historical themes, in particular antique Greek philosophers and writers like Pythagoras, Socrates, Aristotle, Plato, Sophocles and Plutarch.

The inner painting on the inside walls of the church is faithful to the tradition. The Crucifixion of Jesus scene (in the naos, the space where the Liturgy takes place) is regarded as the most valuable work on this theme from all churches in Bucovina. In the apse of the altar, the scene from The Last Supper presents Jesus Christ in the centre. The richness of the figurative and decorative elements is impressive. The specific colour for the Modovita Monastery is yellow.

For their artistic, cultural and historical value five monasteries in Bucovina displaying outside paintings (Humor – 1535, red is dominant; Moldovița – 1537, yellow orange; Arbore – 1541, green; Voroneț – 1547, the famous "Voroneț blue" and Sucevița – 1596, green-red) were awarded in 1975 with the "The Golden Apple" international prize of the Federation of Tourism under the UNESCO patronage. The trophy is kept in the Museum of the Moldovița Monastery.

2.10 Stop 10: Voroneț Monastery (15th century) in Voroneț

by Ovidiu Gabriel Iancu

Location: Voroneț village, located 3 km south of the road between Câmpulung Moldovenesc and Suceava, near the town of Gura Humorului.

Coordinates: N 47°31'1.63" and E 25°51'51"; elevation: 555 m

The monastery was founded by Stephen the Great, in order to celebrate a victory over the Turks. The location was chosen on the place of a former wooden hermitage. The building was built up in three months and three weeks, in the year of 1488. At the beginning, the settlement was a monk monastery. Here a famous hermit, St. Daniil, used to live for a time. The monastic life was interrupted in 1785, after Bukovina was annexed by the Habsburg Empire, and was resumed on in 1991, as a nun monastery (Pascu, 2007).

Widely known throughout Europe as "the Sistine Chapel of the East" due to its inside and outside wall paintings, this monastery offers an abundance of frescoes dominated by an intense blue commonly known as "Voroneț blue" (Fig. 37).

Fig. 36. Moldovița Monastery – 16th century (UNESCO world heritage).

Fig. 37. Voroneț Monastery – 15th century (UNESCO world heritage).

The pigment of the "Voroneț blue" was found to be azurite powder (Istudor, 2008).

On the southern wall there is "Jesse's tree", representing the genealogy of Jesus, starting with the house of David. The votive image is placed on the western wall, inside the church, and was painted during the time of Stephen the Great. The prince, followed by Maria Voichița and Bogdan, the inheritor of the throne, dedicate the Church to Jesus Christ, by means of Saint George, the patron of the monastery.

For their exceptional aesthetic value and the way they express their Christian faith, the Voroneț monastery and the others with outside mural paintings: Moldovița, Humor, Arbore, Sucevița and Probota were included in the UNESCO World Heritage list (Irimia, 2008).

The Church of St. George of the Voroneț Monastery is probable the most famous church of Romania.

2.11 Stop 11: The Humor Monastery (16th century) in Gura Humorului

by Ovidiu Gabriel Iancu

Location: Located in the northern Moldavia, 5–6 km from the town of Gura Humorului, on the valley crossed by the clear waters of the Humor River

Coordinates: N 47°35'36.23"and E 25°51'16"; elevation: 500 m

The church of the monastery (Fig. 38) with its patron "The Assumption of the Holy Virgin" is among the Bukovinean churches with exterior frescos. In 1535, painter Toma from Suceava painted the whole surface of the exterior walls of the church, as part of a programme imposed by Prince Petru Rareş. The dominant colour of the background is reddish brown (Irimia, 2008).

The ruins of the first church of Humor Monastery, or Homor, as it was known at that time, are about 500 m down the road to Pleşa village. A document issued by Alexander the Good in 1415 confirmed that Judge Ivan (Oană) had built a monastery in Homor. During the 15th century, Humor was among the most important monasteries in the country but later in the 16th century it degraded to ruins. The present edifice was built in 1530 by the Great Chancellor Toader Bubuiog and his wife Anastasia, "by the will and support" of Reigning Prince Petru Rareş.

The church, topped by a cross-shaped shingled roof, is without a tower above the nave typical to the churches of the region. The particular element is the open porch with arches, an innovation for that time. This reflects the local building tradition (verandahs, arbours), and the external Renaissance influences (*i.e.* the "loggia"). A novelty is also the vault, located above the tomb room, where valuables were kept in days of distress (Pascu, 2007). The defence tower was erected by the ruler Vasile Lupu in 1641. The painting reflects a perfect harmony between the characteristic elements of the Byzantine art, originated in the theology of the Eastern Church and the skills of the local master (Irimia, 2008). Big part of the painting is dedicated (like the church itself) to Virgin Mary. The most valuable frescoes can be found on the southern side. The monastery was closed in 1786 and was not re-established until 1990.

Fig. 38. Humor Monastery – 15th century (UNESCO world heritage).

2.12 Stop 12: Travertine quarry in Borsec

by Ovidiu Gabriel Iancu & Ciprian Popa

Location: East Carpathians, 1 km E of Borsec village, on the road to Toplița city.

Coordinates: N 46°57'50.70" and E 25°34'30.20"; elevation: 850 m

The travertine quarry (Fig. 39) represents one of the biggest outcrops in Romania of this kind, and the main usage of the rock was for lapidary decoration. The quarry is inside of a Mesozoic metamorphosed area in which two main terranes appear: Rebra Terrane is a tectonic window under the Bucovinian Nappe, represented here by the Tulgheş terrane, with metamorphosed limestones and dolomites cropping out in the middle of Borsec Spa. The Rebra terrane is here composed by metamorphosed carbonates that are in direct connection with the travertines in the Borsec spa (Fig. 40).

The Borsec travertine is found on a large area (1 km²) with up to 40 m in thickness, and it is a result of long-term activity of mineral springs. The widely accepted formation process is the precipitation of carbonate material from water springs forming parallel layers, deposited on the inclined substrata.

The Borsec area belongs to a zone comprising Eastern Europe, Asia Minor and Slavic states territory up to Urals that is particularly rich in carbonate rocks, averaging up to 13%

Fig. 39. Former travertine quarry in Borsec.

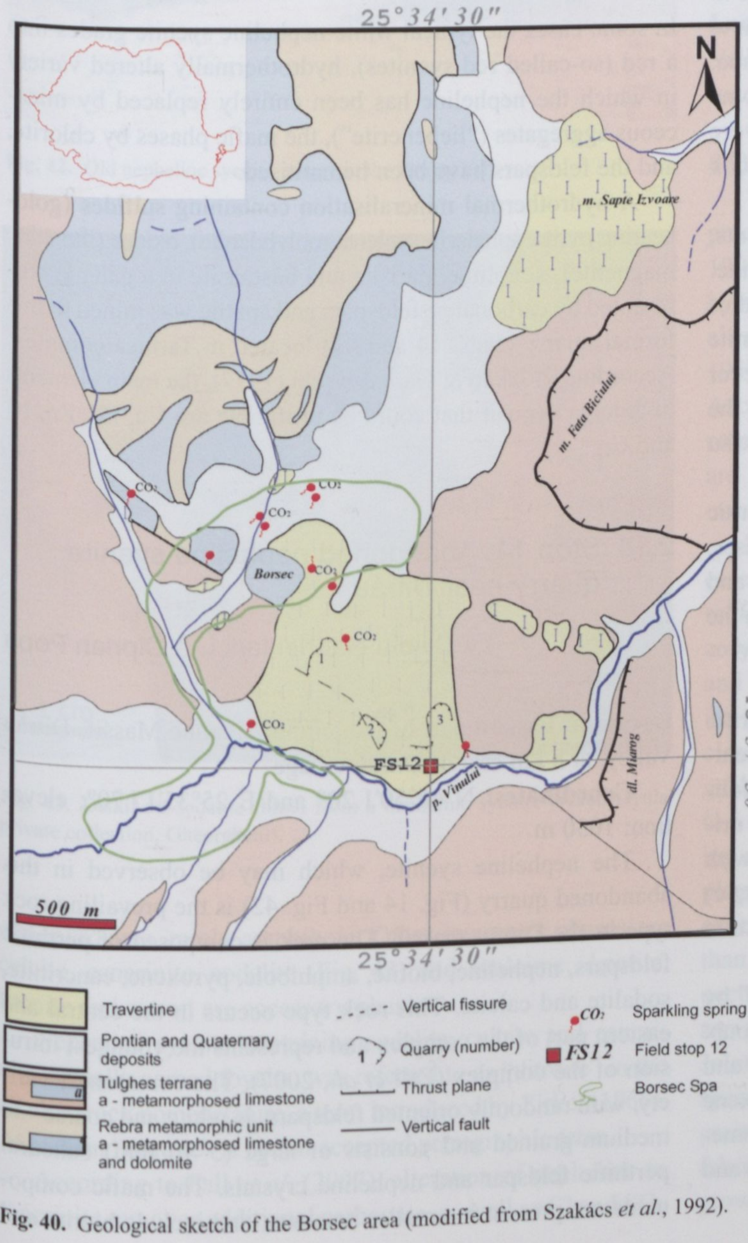

Fig. 40. Geological sketch of the Borsec area (modified from Szakács *et al.*, 1992).

carbonates vs. a 4% global average (Pentecost & Viles, 1994). The area is tectonically dominated by the folds created along the Eastern Carpathians thrust belt, after a post-collisional crustal deformation. The thrusting was accompanied by calc-alkaline to alkali basaltic volcanism active intermittently from Late Miocene to Quaternary (Fielitz & Seghedi, 2005). This event produced also two intramontane pull-apart basins (Borsec/Bilbor–Gheorgheni–Ciuc and Braşov). The Borsec travertine is placed in the first basin, an area also well known for mineral waters, documented since XVIIth century (Patruti *et al.* 2004).

Travertine occurrences in Borsec area

The travertine was extracted in three main quarries (Fig. 40) presenting quasi-horizontal layering. There is only one exception (quarry number one) where there is a dipping in the western side up to 35°. A fracture is cutting the entire quarry with a width of 25–35 cm, which was subsequently filled with grey clay marl. The occasional empty spaces are filled with concentric radial fibrous carbonate aggregates of orange or green colour.

The main travertine body is in the Scaunul Rotund Hill on an area of ~1 km² with an apparent thickness of 130m. The thickness is variable along the travertine exposure. On along the Valea Vinului gorge there is a clear exposure of the travertine versant with heights of many tens of meters. There are smaller occurrences disposed radially around the main body mostly along Hanţahal and Nadaş streams.

The occurrence thickness and dip is controlled by the country rock that dips northward, where metamorphosed carbonates outcrops near the surface.

Macroscopic appearance: Travertine at Borsec has a general layered appearance. The layering is given by band alternation with thicknesses from mm up to 1.5 cm. The layering is enhanced by variations of colour (white-brown) that record changes in the water composition (mainly Fe). There are empty spaces following the general trend of layering.

Microscopic features: There are two kinds of carbonate texture type that is connected to the layering itself and the space filling along fissures. The travertine is made mainly of a micritic carbonate and a microsparitic one (translucent to obscure). The later consists of structures formed originally by Cyanobacteria or "blue algae". A limpid sparitic carbonate occupies the interstices and empty spaces, as well as encapsulating microscopic scale biotic remains. The microsparitic and micritic dark appearance is given by the organics and clays trapped inside the structure. There are typical stromatolitic algal structures with dendritic and growing structures. The structures appear to grow starting from the previous layer or on the walls of interstices.

2.13 Stop 13: Old Jolotca quarry at Jolotca

by Ovidiu Gabriel Iancu & Ciprian Popa

Location: On the local road from Jolotca (Orotva) Creek, at 3.5 km E from Jolotca Village

Coordinates: N 46°52'9.87" and E 25°33'7.88"; elevation: 870 m

The old Jolotca quarry is located in the northern part of the Ditrău massif.

According to Morogan *et al.* (2000) the Jolotca area has an asymmetrical structure in which the alkali gabbro ± alkali diorite rocks are concentrated in the west whereas quartz syenites, syenites and alkali granites predominate to the east. West of Jolotca there is extreme heterogeneity involving intricate mingling of alkali gabbro and alkali diorite with quartz syenite. Globular to lenticular bodies of mafic rocks with crenulated, lobate margins, vary in diameter from a few centimetres to over one metre; these are enclosed in, and veined by, felsic rocks in the manner of net-veined intrusions. The mafic bodies seem to have been injected as melt `lens-like' into a leucocratic magma. The whole ensemble appears then to have undergone some compaction whereby originally equant 'lens-like' were deformed (flattened) to variable degrees. The deformation took place in a sub-solidus stage of magmatic consolidation.

With an increase in the ratio of salic to mafic components, these mixed rocks grade into quartz syenite and granite. Within zone of mixed rocks in the Jolotca area discrete bodies of ultramafic rock (kaersutite peridotite, olivine pyroxenite and hornblendite) occur. Olivine-free ultramafic rocks occur as lenticular masses, up to hundreds of metres across, in the alkali gabbros and diorites of both the Jolotca and the Ditrău *s.s.* areas, but are less common in the latter.

According to Anastasiu & Constantinescu (1979), the dioritic rocks from Jolotca form stratiform rock bodies, schlieric lenses, nests, and show great textural variety ("pegmatoid", normal and micrograined, oriented and non-oriented textures). Based on the colour index (M), the authors described leucodiorites (M < 25%) and diorites (M = 25–50%).

Pál Molnár (2000), classified the rocks of the dioritic group as: a) Meladiorites, including meladiorites with oriented texture, meladiorites with non-oriented texture and "foliate-like" meladiorites; b) Diorites, including diorites with oriented texture, diorites with non-oriented texture, diorites with feldspar schlieren and diorites with feldspar aggregates; c) Leucodiorites, including leucodiorites with oriented texture and leucodiorites with non-oriented texture.

Diorites with oriented texture, called "gneissic diorites" by Ianovici *et al.* (1968) are predominant among the dioritic group. According to Streckeisen & Hunziker (1974), plagioclase and amphibole are the main constituents, but biotite, pyroxene (diopsidic augite, Ti-rich augite, aegirine-augite), and sometimes even K-feldspar (microcline-perthite and antiperthite) and nepheline occur in variable amounts in these rocks.

Fig. 41. Alkali diorite with oriented texture in the Jolotca quarry.

In some cases the typical white nepheline syenite grades into a red (so-called red syenites), hydrothermally altered variety in which the nepheline has been entirely replaced by micaceous aggregates ("liebenerite"), the mafic phases by chlorite, and the feldspars have been hematitised.

A hydrothermal mineralisation containing sulfides (gold-bearing pyrite, sphalerite, galena, molybdenite), oxides (ilmenite, magnetite), xenotime, parisite and bastnäsite in a gangue represented by carbonates, feldspars and apatite was mined in this former quarry (Figs. 14 and 41) located in Tarnica complex. According to Jakab & Garbaşevschi (1977), the main elements of Jolotca deposit that could be profitable are Cu, Pb, Zn, Ni and Co.

2.14 Stop 14: Abandoned nepheline syenite quarry near Ditrău

by Ovidiu Gabriel Iancu & Ciprian Popa

Location: Eastern part of the Ditrău Alkaline Massif, Ditrău Valley, at 8 km east of Ditrău village

Coordinates: N 46°50'1.20" and E 25°35'17.70"; elevation: 1030 m

The nepheline syenite, which may be observed in this abandoned quarry (Fig. 14 and Fig. 42) is the prevailing rock type in the Ditrău massif. The rock is composed of perthitic feldspars, nepheline, biotite, amphibole, pyroxene, cancrinite, sodalite and calcite. This rock type occurs in the central and eastern part of the complex and represents the youngest intrusion of the complex (Fall *et al.*, 2007). The commonest variety, with randomly oriented feldspars, is white and coarse - to medium-grained and consists of large (5–10 mm) euhedral perthitic feldspar and nepheline crystals. The mafic components are present in smaller amounts, and include biotite and

Fig. 42. Old nepheline syenite quarry in the Ditrău Valley.

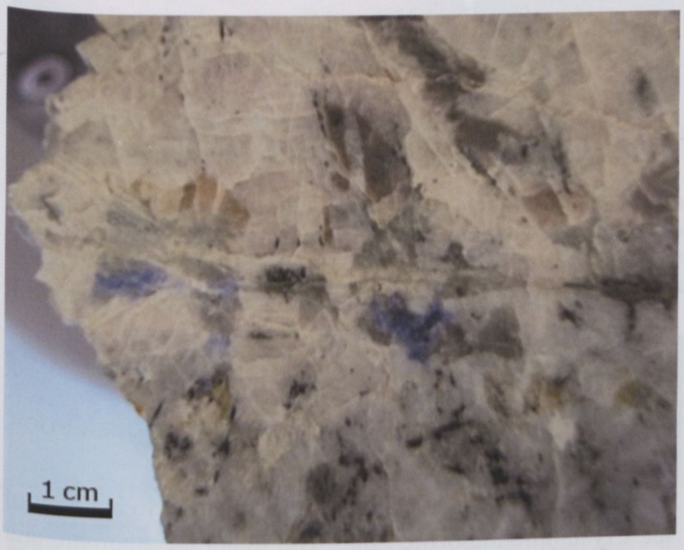

Fig. 43. Detail on sodalite (blue) from a nepheline syenite (Jakab Gyula private collection, Gheorgheni).

clinopyroxene, rarely amphibole. Other important phases are calcite, cancrinite, sodalite (Fig. 43) and analcime. Apatite, titanite and zircon are accessory phases.

Nepheline syenite containing sodalite, calcite and cancrinite, actually named foyaite, was referred to as "ditroite" in the alkaline rock nomenclature, a term introduced by Zirkel (1866). At present "ditroite" is not an accepted petrographic term.

According to Fall *et al.* (2007), alteration of nepheline to cancrinite removes additional carbonate, as well as Cl and SO_4 ions. The formation of sodalite by alteration of nepheline (or albite) removes NaCl from the aqueous solution. The alteration of albite to produce sodalite also releases silica to the solution, which is involved in the alteration of nepheline to produce analcime. Late crystallization of the hydrous minerals biotite and amphibole is related to the increasing activity of water in the melt and in the coexisting aqueous phase. This interpretation suggests that the nepheline syenite melt achieved volatile saturation soon after crystallization began, and that an active magmatic hydrothermal system existed during the crystallization history of the nepheline syenites of the Ditrău Alkaline Massif.

2.15 Stop 15: Outcrop of "ditro-essexite" near Ditrău

by Ovidiu Gabriel Iancu & Ciprian Popa

Location: Eastern part of the Ditrău Alkaline Massif, Ditrău Valley, at 6.6 km east of Ditrău village on the Ditrău–Tulgheş road.

Coordinates: N 46°52'9.87"and E 25°33'7.88"; elevation: 870 m.

The outcrop is located in the central part of the massif, more precisely in the so-called Güdücz complex (Kräutner & Bindea, 1998) – Figs. 14 and 44. The rocks of this complex consist of hybrid alkaline gabbro, diorite and monzonite metasomatically altered by nepheline syenites, for which Streckeisen (1952, 1954, 1960) used the comprehensive term "Ditro-essexites". According to Streckeisen & Hunziker (1974), these rocks are commonly foliated, at places even distinctly schistosic. They are intricately intermingled with bands and veins of massive, even pegmatoid syenite and nepheline syenite.

Streckeisen (1960) suggested the use of the term "Ditro-essexites" for the whole heterogeneous mesocratic suite of rocks, including gabbros, diorites, monzodiorites and monzosyenites. Morogan *et al.* (2000) used the terms alkali gabbro and alkali diorite, together with monzodiorite and monzosyenite to sub-divide these "Ditro-essexites". The same authors classified the alkali gabbros into two subgroups. The alkali gabbro I regards medium- to coarse-grained rocks (crystals up to 5 mm) typically with granular or subophitic texture, consisting of amphibole (kaersutite and/or Ti-rich ferroan pargasite), plagioclase (An_{60-23}), titanite and apatite. Diopside is scarce, except in some drill holes in Ditrău where it is more abundant than the amphibole. Titanite is plentiful (> 20 %) and large, occurring in crystals up to 1 cm. Ilmenite, magnetite and zircon are accessory minerals. Alkali gabbro II is confined to the Jolotca area (Fig. 14), where it occurs as lenses within quartz syenites. It is more fine-grained (1 ± 0.3 mm or even < 1 mm grain-size) than alkali gabbro I and sometimes shows quenched fabric, with dendritic amphibole (magnesiohastingsite) intergrown with apatite, titanite, biotite and plagioclase.

Fig. 44. Outcrop in the Güdücz complex (white nepheline syenites and alkaline gabbros are clearly visble).

Day 5

2.16 Stop 16: Mineral and rock collection in the "Tarisznyás Márton" Museum in Gheorgheni

by Gyula Jakab

Location: centre of Gheorgheni city, in the main building of the "Tarisznyás Márton" Museum

Coordinates: N 46°43'13.11" and E 25°36'0.60"; elevation: 800 m

The mineral and rock collection exhibited in the "Tarisznyás Marton" Museum in Gheorgheni is a private collection, donated by Dr. Gyula Jakab, geologist. The exhibited was opened to the public in 2008. It consists of several rooms and individual collections, such as:

Room 1. Geology of the Ditrău Alkaline Massif:

- A 3D geological map (scale 1:10,000) of the area (Fig. 45b)
- Representative drill-cores from four geological structure research drilling of various depth (from 650 m to 1400 m)
- Characteristic rock and ore samples etc.
- Set of pictures taken under the polarizing microscope showing minerals found in the Ditrău Massif (Fig. 45c)

Room 2. Characteristic fossils from the Paleozoic, Mesozoic and Cenozoic.

Room 3. Mineralogical and geological equipment and mining tools.

Room 4. Igneous, metamorphic and sedimentary rocks from different parts of Romania and from abroad. More than 60 plates of ornamental rocks from different párts of the world are also displayed (Fig. 45d).

Room 5. "Mine flowers", *i.e.* large crystals of various oxides, carbonates, sulphates, sulphides. Minerals arranged according to systematic classification of Strunz (Fig. 45a), cut gemstones (Fig. 45e) and fluorescent minerals are also displayed.

2.17 Stop 17: Dolomite quarry in Voşlăbeni

by Victor Şabliovschi & Marcel Răileanu

Location: Voşlăbeni dolomite quarry (Fig. 46) is located in the eastern part of Voşlăbeni locality (9 km south of Gheorgheni city), NE of Cocoşelul peak (1112 m) in the Giurgeu Mts. (Fig. 47).

Coordinates: N 46°38'2.50" and E 25°38'26.63"; elevation: 890 m

The quarry exposes rocks belonging to the Rebra Unit of the Crystalline-mesozoic Zone. The Rebra metamorphic unit (Balintoni *et. al.*, 2009) from the Rebra terrane was denominated by Kräutner in 1968. It could be divided into several sub-units ("formations") named by Kräutner *et al.* (1982) (from bottom to top): Izvorul Roşu, Voşlobeni and Ineu "formations".

The *Voşlobeni sub-unit* is represented by a thick pile of carbonatic rocks with intercalations of paragneisses, white and black quartzites. On large areas, at the top and the bottom of the sub-unit amphibolites or thick amphibolitic gneisses can be found.

Voşlăbeni metamorphosed dolomites and dolomitic limestones are exposed on the southwestern side of Cocoşelul peak opening towards Mureş Valley (Fig. 47). They have a

Fig. 45. Exhibition of the ineralogical collection of Gyula Jakab in the „Tarisznyás Márton" Museum, Gheorgheni: a) Showcases presenting the systematic collection, b) 3D geological map of the Ditrău Alkaline Massif (scale 1:10,000), c) Display of polarized light microscopic images of minerals and rocks from the Ditrău massif, d) Ornamental rocks from different parts of the world, e) Gemstones.

grey-white to yellow colour, the white being characteristic to freshly exposed dolomite.

Average chemical composition of metamorphosed dolomites (in wt%) is: CaO = 33.10, MgO = 21.80, SiO_2= 1.60, Fe_2O_3=0.16, Al_2O_3= 0.14, Na_2O = 0.16, K_2O = 0.04, LOI = 43.87 and traces of SO_3 and P_2O_5 (Zsakó & Hints, 1998). Dolomite crystallinity is variable from fine-grained to coarse-grained. Large (up to 5–10 cm) prismatic or radialy fibrous tremolite crystals may be observed occasionally. The metamorphosed dolomites are processed by a crushing and washing plant belonging to Harghita Mining Company (S.C. Exploatarea Minieră Harghita S.A.). Various granular and powder grades of dolomite are delivered for the following areas: steel industry, chemical industry, road and railway construction, glass production, agricultural amendment, ornamental rocks, ceramics.

2.18 Stop 18: Cluj-Napoca: Babeş-Bolyai University, Mineralogical Museum (from Ionescu & Hoeck, 2010)

Location: center of Cluj-Napoca (Fig. 48), in the main building of the "Babeş-Bolyai" University.

Coordinates: N 46°45.130' and E 23°34.450'

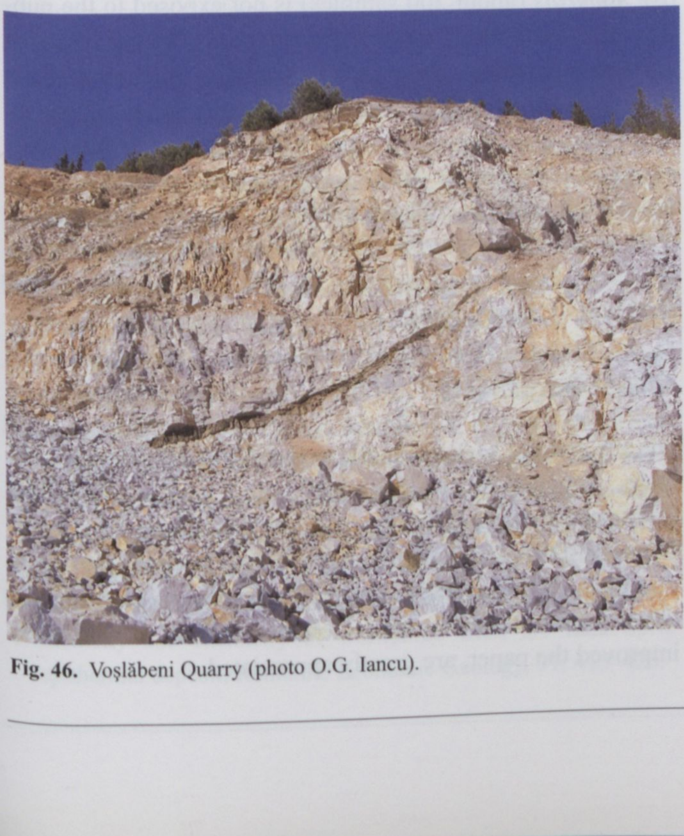

Fig. 46. Voşlăbeni Quarry (photo O.G. Iancu).

The Mineralogical Museum contains a rich collection of mineral specimens, accumulated during its long history. The museum was established as purely academic collection in 1919, on the basis of the mineral and rock collection earlier jointly owned by the Transylvanian Museum Association and the Institute of Mineralogy and Geology of the "Ferenc József" University. Subsequently, the collections were reorganized, continuously and substantially enriched by donations, exchanges, acquisitions and samples collected by the professors and students in geology (Ionescu & Tămaş, 2003; Ionescu *et al.,* 2009a). The Chair of Mineralogy scientifically coordinates the museum. Rare specimens (very large crystals of pyrite, tetrahedrite, aragonite, halite, quartz and gypsum), as well as rare mineral species (native tellurium, tellurides, some silicates), the cut gemstones and the meteorites are among the main attractions in the museum.

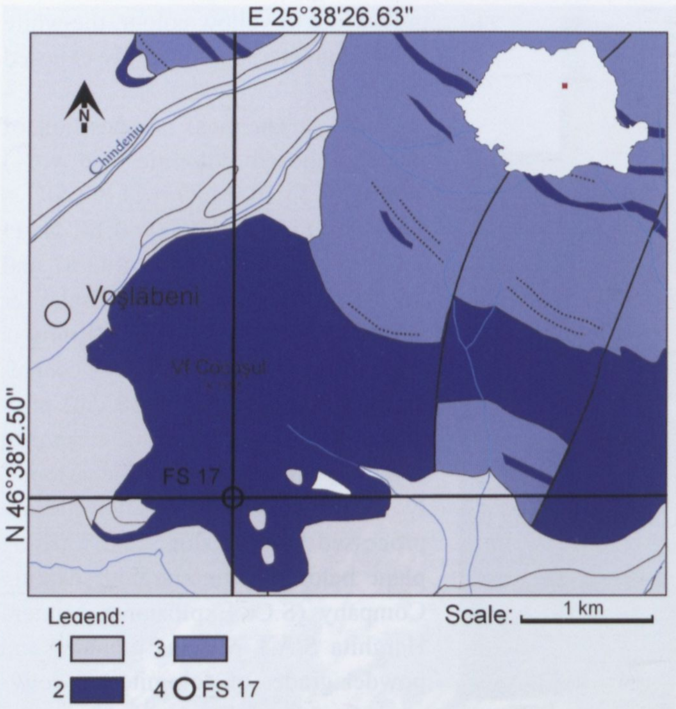

Fig. 47. Geologic sketch of the Voşlăbeni area (modified from the Geological map of Romania, 1:50.000, Voşlăbeni sheet, Mureşan *et. al.*, 1986). Legend: 1 – Quaternary deposits; 2 – Rebra metamorphic unit (Voşlobeni sub-unit); 3 – Rebra metamorphic unit (Ineu sub-unit); FS 17 – field stop 17.

Fig. 48. Centre of Cluj-Napoca (photo C. Ionescu).

The museum houses about 25,000 samples, grouped in the following main collections: "Native gold" (450 samples), "Meteorites" (210 samples), "Systematic collection" (about 10,000 samples), "Regional collection" (about 1,500 samples), "Cut gemstones" (250 cut gems), "Romanian gemstones" (about 3,500 samples), "Minerals discovered for the first time in Romania" (40 samples), "Radioactive minerals" (about 200 samples), "Ore minerals" (5,000 samples), "The crystallographic collection" (1,500 samples) and "The petrographic collection" (1,000 rock samples).

The *Native gold* collection, with 450 samples (Fig. 49a), represents the second largest gold collection in Romania, whereas the collection of 204 meteorites is unique in Romania. Fragments from five Romanian meteorites are displayed, including the famous Mociu (Mocs) meteorite. The largest piece, weighting 35.7 kg (Fig. 49b), fell down in 1882 at 40 km east of Cluj-Napoca.

The systematic collection contains about 10,000 samples from the world's most important occurrences, illustrating over 800 mineral species ordered according to the Strunz classification (Figs. 49c,d). This collection represents the greatest number of different minerals species gathered in a single museum, in Romania. *The regional collection* consists of 1,500 mineral samples collected from over 70 mines, outcrops and quarries from Romania.

The cut gems collection (250 cut gems), the richest in Romania, is displayed in an original cupboard from the XIX[th] century. It contains the main gems, such as diamond, corundum (with both ruby and sapphire varieties), beryl (emerald, aquamarine), garnets, tourmaline, quartz (amethyst, citrine, rock crystal, and agate), opals (precious opal, fire opal), spinels, zircon, turquoise, as well as pearls and corals. Synthetic counterparts of the main gemstones can also be seen.

The collection of the Romanian gemstones consists of 3,500 samples (Ionescu *et al.*, 2009a), from which only 1,200 cabochon-cut gemstones, mainly quartz, chalcedonies, agates, opals, jaspers, are displayed. This collection was set up in 1987, based on the specimens collected from 90 occurrences by the professors of the Geology Department.

The collection of the minerals discovered for the first time in Romania contains 18 mineral species, *e.g.* native tellurium, sylvanite, nagyagite, krennerite, petzite, fizélyite, fülöppite, semseyite, andorite, tellurite *a.o. The collection of radioactive minerals* (about 200 samples) is not exposed to the public and is used only for scientific purposes. *The ore minerals collection* contains about 5,000 samples originating from Romania and foreign countries, genetically grouped in: orthomagmatic, pegmatitic, skarn, hydrothermal, metamorphic and sedimentary deposits. *The crystallographic collection* (about 1,500 samples) consists of 750 natural crystals as well as casts. *The petrographic collection* (1,000 rock samples from Europe) is located in the Microscopy room and is used mainly for teaching.

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Fig. 49. Images from the Mineralogical Museum, Cluj-Napoca (from Ionescu *et al.*, 2009): a) Dendritic gold crystal from Roşia Montană (length of the specimen 2 cm, b) The Mociu (Mocs) chondritic meteorite (width of the sample 35 cm, c) Detail from the systematic exhibition, d) Bucium pyrite (length of the sample 66 cm).

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Appendix – Itinerary for IMA2010 RO1 Field trip

Monday, August 16, 2010 (Day 1)

07.00–14.30	Travel from Budapest to Baia Mare (Budapest – Polgár – Nyíregyháza – Petea – Satu Mare – Baia Mare)
14.30–16.00	Accomodation and lunch at Rivulus Hotel
16.00–16.30	Travel to Şurdeşti
16.30–17.15	Stop 1: Şurdeşti wooden church – 18th century (UNESCO World Heritage)
17.45–18.45	Stop 2: Baia Mare museum of mineralogy
19.00–21.30	Visit to the old town and dinner at the Korvin medieval restaurant

Tuesday, August 17, 2010 (Day 2)

08.00–08.30	Travel from Baia Mare to Baia Sprie
08.30–11.30	Stop 3: Baia Sprie epithermal ore deposit – Dealul Minei open pit
11.45–12.45	Stop 4: Laleaua Albă Quarry – Neogene igneous complex (dacitic and andesitic rocks of magma mixing and mingling origin)

13.15–14.30	Şuior touristic resort – lunch break
14.30 -21.00	Travel to Tihuţa Pass
21.00	Accomodation and dinner at "Dracula's Castle" Hotel

Wednesday, August 18, 2010 (Day 3)

08.00–08.50	Travel to Vatra Dornei
09.00–11.00	Stop 5: Mănăila quarry, metamorphosed base metal deposit: pyrite, sphalerite, chalcopyrite, galena, tetrahedrite, covelline, bornite, native gold
11.00–12.00	Travel to Vatra Dornei
12.00–13.00	Lunch break
13.00–14.00	Travel to Negoiul Românesc "Sulphur" Quarry
14.00–15.30	Stop 6: "Sulphur" Quarry (pyroxene andesite lava/pyroclastics alternations with intense hydrothermal alteration, breccia bodies)
15.30–17.00	Travel to Ulm quarry
17.00–18.00	Stop 7: metamorphosed Mn deposit in Ulm Quarry (Fe-rhodochrosite, Mn-amphibole, spessartine, stilpnomelane, rhodonite, pyroxmangite and tephroite)
18.00–19.00	Stop 8: Dorna Arini Monastery
19.00–20.00	Dinner at Dorna Arini Monastery, accommodation

Thursday, August 19, 2010 (Day 4)

08.00–09.30	Stop 9: Moldoviţa Monastery – 16th century (UNESCO world heritage)
09.30–10.20	Stop 10: Voroneţ Monastery – 15th century (UNESCO world heritage)
10.20–11.10	Stop 11: Humorului Monastery – 16th century (UNESCO world heritage)
11.10–13.15	Travel to Borsec via Ostra, Broşteni, Tulgheş
13.15–14.00	Lunch break in Grinţieş
14.00–14.30	Travel to Borsec
14.30–15.30	Stop 12: Travertine quarry, Borsec (includes 1000 m walk on a mild slope)
15.30–16.30	Travel to Jolotca Valley (Ditrău Massif)
16.30–17.00	Stop 13: Old Jolotca quarry: diorites, red syenites
17.00–17.30	Travel to Ditrău Valley (Ditrău Massif)
17.30–18.00	Stop 14: Abandoned Ditrău quarry: alkaline syenites with potassic feldspar, nepheline, albite, aegirine, biotite, amphibole, titanite, cancrinite, sodalite, and analcime
18.00–18.40	Stop 15: Outcrop of "ditro-essexite" in the Ditrău Massif
18.40–19.00	Travel to Gheorgheni
19.00–20.00	Dinner at Rubin Hotel, accommodation

Friday, August 20, 2010 (Day 5)

08.00–09.00	Stop 16: Gheorgheni "Tarisznyás Márton" Museum, exhibition of the mineral collection of Gyula Jakab
09.00–09.30	Travel to Voşlobeni
09.30–10.30	Stop 17: Voşlobeni Quarry (metamorphosed dolomites with large tremolite crystals)
09.30–13.00	Travel to Cluj-Napoca (via Sovata, Târgu Mureş)
13.00–14.30	Lunch break
14.30–16.30	Stop 18: "Babeş-Bolyai" University, Cluj-Napoca, Mineralogical Museum
16.30–20.30	Walking tour in Cluj-Napoca and dinner
21.00	Accommodation at the "Babeş-Bolyai" University Hotel

Saturday, August 21, 2010

08.00–15.00	Travel to Budapest